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Development Document for the Effluent Limitations and Guidelines for the Ore Mining and Dressing Point Source Category. Volume II

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for
EFFLUENT LIMITATIONS GUIDELINES
and
NEW SOURCE PERFORMANCE STANDARDS
for the
ORE MINING AND DRESSING
POINT SOURCE CATEGORY

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Douglas M. Costle
Administrator

Thomas C. Jorling
Assistant Administrator for
Water and Hazardous Materials

Swep Davis
Deputy Assistant Administrator
for Water Planning and Standards

Robert B. Schaffer
Director, Effluent Guidelines Division

Baldwin M. Jarrett
Project Officer

Ronald G. Kirby
Assistant Project Officer

July, 1978

Effluent Guidelines Division
Office of Water and Hazardous Materials
U.S. Environmental Protection Agency
Washington, D.C. 20460

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Ronald G. Kirby, Assistant Project Officer

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Effluent Guidelines Division
Office of Water and Waste Management
U. S. Environmental Protection Agency
401 M Street, S. W.
Washington, D. C. 20460

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This document presents the findings of an extensive study of the ore mining and dressing industry, for the purpose of developing effluent limitations guidelines for existing point sources and standards of performance and pretreatment standards for new sources, to implement Sections 304, 306, and 307 of the Federal Water Pollution Control Act, as amended in 1977 by the Clean Water Act, P.L. 95-217.

Effluent limitations guidelines are set forth for the degree of effluent reduction attainable through the application of the best practicable control technology currently available (BPCTCA) and the degree of effluent reduction attainable through the application of the best available technology economically achievable (BATEA) which must be achieved by existing point sources. The standards of performance for new sources are set forth for the degree of effluent reduction which is achievable through the application of the best available demonstrated control technology processes, operating methods, or other alternatives.

Supporting data and rationale for development of the proposed effluent limitation guidelines and standards of performance are contained in this report (Volumes I and II).

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ABSTRACT

This document presents the findings of an extensive study of the ore mining and dressing industry, for the purpose of developing effluent limitations guidelines for existing point sources and standards of performance and pretreatment standards for new sources, to implement Sections 304, 306 and 307 of the Federal Water Pollution Control Act, as amended (33 U.S.C. 1551, 1314, and 1316, 86 Stat. 816 et. seq.) (the "Act").

Effluent limitations guidelines contained herein set forth the degree of effluent reduction attainable through the application of the best practicable control technology currently available (BPCTCA) and the degree of effluent reduction attainable through the application of the best available technology economically achievable (BATEA) which must be achieved by existing point sources by July 1, 1977, and July 1, 1983, respectively. The standards of performance and pretreatment standards for new sources contained herein set forth the degree of effluent reduction which is achievable through the application of the best available demonstrated control technology, processes, operating methods, or other alternatives.

Based upon the application of the best practicable control technology currently available, 13 of the 41 subcategories for which separate limitations are suggested can be operated with no discharge of process wastewater. With the best available technology economically achievable, 21 of the 41 subcategories for which separate limitations are proposed can be operated with no discharge of process wastewater to navigable waters. No discharge of process wastewater pollutants is also achievable as a new source performance standard for 21 of the 41 subcategories.

Supporting data and rationale for development of the proposed effluent limitation guidelines and standards of performance are contained in this report (Volumes I and II).

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SECTION VII

CONTROL AND TREATMENT TECHNOLOGY

INTRODUCTION

Waterborne wastes from the mining of metal-ore minerals consist primarily of suspended solids and metals in solution. The mineralogy of the ore and associated overburden and the chemical character of percolating mine waters influence the metal content of mine wastewater, while solids suspended in the wastewater are influenced by the methods of mining as well as the physical nature and general geologic characteristics of the ore.

The wastewater from ore milling and beneficiation operations is characterized by high suspended-solid loads, heavy metals in solution, dissolved solids, and process reagents added during the concentration process. Impoundment and settling pond facilities with lime addition for pH control or to obtain improved settling characteristics primarily for suspended solids removal, are in widespread use in the treatment of mill effluents. This treatment technology is effective in removal of other wastewater components as well. Space requirements and location often affect the utilization of this widespread treatment technology and dictate the economics of the operations. Other treatment technologies for removal of dissolved components are, for the most part, well-known but are not in widespread use throughout the industry.

The control and treatment of the waterborne wastes found in the mining and beneficiation of metal-ore minerals are influenced by several factors:

(1) Large volumes of mine water and wastewater from ore-concentrating operations to be controlled and treated.

(2) Seasonal, as well as daily, variations in the amount and chemical characteristics of mine water influenced by precipitation, runoff, and underground-water contributions.

(3) Differences in wastewater composition and treatability caused by ore mineralogy and processing techniques and reagents.

(4) Geographic location and climatic conditions. (Treatment and control technology selection and economics are influenced by the amount of water to be handled.)

CONTROL PRACTICES AND TECHNOLOGY

Control technology, as discussed in this report, includes techniques and practices which may be employed before, during, and after the actual mining or milling operation to reduce or eliminate adverse environmental effects resulting from the discharge of mine or mill wastewater. Effective pollution-control planning can reduce pollutant contributions from active mining and milling sites and can also minimize post-operational pollution potential. Because pollution potential may not cease with closure of a mine or mill, control measures also refer to methods practiced after an operation has terminated production of ore or concentrated product. The presence of pits, storage areas for spoil (non-ore material, or waste), tailing ponds, disturbed areas, and other results or effects of mining or milling operations necessitates integrated plans for reclamation, stabilization, and control to return the affected areas to a condition at least fully capable of supporting the uses which it was capable of supporting prior to any mining and to achieve a stability not posing any threat of water diminution, or pollution and to minimize potential hazards associated with closed operations.

Mining Techniques

Mining techniques can effectively reduce amounts of pollutants coming from a mine area by containment within the mine area or by reducing their formation. These techniques can be combined with careful reclamation planning and implementation to provide maximum at-source pollution control.

Pollution-control technology in underground mining is largely restricted to at-source methods of reducing water influx into mine workings and segregation of mine water from working areas. Infiltration from strata surrounding the workings is the primary source of water, and this water reacts with air and sulfide minerals within the mines to create acid, pH conditions and, thus, to increase the potential for solubilization of metals. Underground mines are, therefore, faced with problems of water handling and mine-drainage treatment. Open-pit mines, on the other hand, receive both direct rainfall and runoff contributions, as well as infiltrated water from intercepted strata.

Infiltration in underground mines generally results from rainfall recharge of a ground-water reservoir. Rock fracture zones, joints, and faults have a strong influence on ground-water flow patterns since they can collect and convey large volumes of water. These zones and faults can intersect any portion of an underground mine and permit easy access of ground water. In some mines, infiltration can result in huge volumes of water that must be handled and treated. Pumping can be a major part of the mining operation in terms of equipment and expense--particularly, in mines which do not discharge by gravity.

Water-infiltration control techniques, designed to reduce the amount of water entering the workings, are extremely important in underground mines located in or adjacent to water-bearing strata. These techniques are often employed in such mines to decrease the volume of water requiring handling and treatment, to make the mine workable, and to control energy costs associated with dewatering. The techniques include pressure grouting of fissures which are entry points for water into the mine. New polymer-based grouting materials have been developed which should improve the effectiveness of such grouting procedures. In severe cases, pilot holes can be drilled ahead of actual mining areas to determine if excessive water is likely to be encountered. When water is encountered, a small pilot hole can be easily filled by pressure grouting, and mining activity may be directed toward non-water-contributing areas in the formation. The feasibility of such control is a function of the structure of the ore body, the type of surrounding rock, and the characteristics of ground water in the area.

Decreased water volume, however, does not necessarily mean that wastewater pollutant loading will also decrease. In underground mines, oxygen, in the presence of humidity, interacts with minerals on the mine walls and floor to permit pollutant formation e.g., acid mine water, while water flowing through the mine transports pollutants to the outside. If the volume of this water is decreased but the volume of pollutants remains unchanged, the resultant smaller discharge will contain increased pollutant concentrations, but approximately the same pollutant load.

Rapid pumpout of the mine can, however, reduce the contact time and significantly reduce the formation of pollutants.

Reduction of mine discharge volume can reduce water handling costs. In cases of acid mine drainage, for example, the same amounts of neutralizing agents will be required because pollutant loads will remain unchanged. The volume of mine water to be treated, however, will be reduced significantly, together with the size of the necessary treatment and settling facilities. This cost reduction, along with cost savings which can be attributed to decreased pumping volumes (hence, smaller pumps, lower energy requirements, and smaller treatment facilities), makes use of water infiltration-control techniques highly desirable.

Water entering underground mines may pass vertically through the mine roof from rock formation above. These rock units may have well-developed joint systems (fractures along which no movement occurs), which tend to facilitate vertical flow. Roof collapses can also cause widespread fracturing in overlying rocks, as well as joint separation far above the mine roof. Opened joints may channel flow from overlying aquifers (water-bearing rocks) a flooded mine above, or even from the surface.

Fracturing of overlying strata is reduced by employing any or all of several methods: (1) Increasing pillar size; (2) Increasing support of the roof; (3) Limiting the number of mine entries and reducing mine entry widths; (4) Backfilling of the mined areas with waste material.

Surface mines are often responsible for collecting and conveying large quantities of surface water to adjacent or underlying underground mines. Ungraded surface mines often collect water in open pits when no surface discharge point is available. That water may subsequently enter the groundwater system and then percolate into an underground mine. The influx of water to underground mines from either active or abandoned surface mines can be significantly reduced through implementation of a well-designed reclamation plan.

The only actual underground mining technique developed specifically for pollution control is preplanned flooding. This technique is primarily one of mine design, in which a mine is planned from its inception for post-operation flooding or zero discharge. In drift mines and shallow slope or shaft mines, this is generally achieved by working the mine with the dip of the rock (inclination of the rock to the horizontal) and pumping out the water which collects in the shafts. Upon completion of mining activities, the mine is allowed to flood naturally, eliminating the possibility of acid formation caused by the contact between sulfide minerals and oxygen. Discharges, if any, from a flooded mine should contain a much lower pollutant concentration. A flooded mine may also be sealed.

Surface-Water Control

Surface water control is an integral part of any mining operation, either surface or underground. Surface water interfers with operations in working areas and this must be diverted from the site or removal by other means will be necessary resulting in some cost. Surface water control to benefit the mining operation will also result in pollution control by preventing runoff from coming into contact with disturbed areas.

Prior planning for waste disposal is also required to control pollution from runoff. Disposal sites should be isolated from surface flows and impoundments to prevent or minimize pollution potential. In addition, several techniques are practiced to prevent water pollution:

(1) Construction of a clay or other type of liner beneath the planned waste disposal area to prevent infiltration of surface water (precipitation) or water contained in the waste into the ground-water system.

(2) Compaction of waste material to reduce infiltration.

(3) Maintenance of uniformly sized refuse to enhance good compaction (which may require additional crushing).

(4) Construction of a clay liner over the material to minimize infiltration. This is usually succeeded by placement of topsoil and seeding to establish a vegetative cover for erosion protection and runoff control.

(5) Excavation of diversion ditches surrounding the refuse disposal site to exclude surface runoff from the area. These ditches can also be used to collect seepage from refuse piles, with subsequent treatment, if necessary.

Surface runoff in the immediate area of beneficiation facilities presents another potential pollution problem. Runoff from haul roads, areas near conveyors, and ore storage piles is a potential source of pollutant loading to nearby surface waters. Several current industry practices to control this pollution are:

(1) Construction of ditches surrounding storage areas to divert surface runoff and collect seepage that does occur.

(2) Establishment of a vegetative cover of grasses in areas of potential sheet wash and erosion to stabilize the material, to control erosion and sedimentation, and to improve the aesthetic aspects of the area.

(3) Installation of hard surfaces on haul roads, beneath conveyors, etc., with proper slopes to direct drainage to a sump. Collected waters may be pumped to an existing treatment facility for treatment.

Another potential problem associated with construction of tailing-pond treatment systems is the use of existing valleys and natural drainage areas for impoundment of mine water or mill process wastewater. The capacity of these impoundment systems frequently is not large enough to prevent high discharge flow rates--particularly, during the late winter and early spring months. The use of ditches, flumes, pipes, trench drains, and dikes will assist in preventing runoff caused by snowmelt, rainfall, or streams from entering impoundments. Very often, this runoff flow is the only factor preventing attainment of zero discharge. Diversion of natural runoff from impoundment treatment systems, or construction of these facilities in locations which do not obstruct natural drainage, is therefore, desirable.

Ditches may be constructed upslope from the impoundment to prevent water from entering it. These ditches also convey water away and reduce the total volume of water which must be treated. This may result in decreased treatment costs, which could offset the costs of diversion.

Segregation or Combination of Mine and Mill Wastewater

A widely adopted control practice in the ore mining and dressing industry is the use of mine water as a source of process water. In many areas, this is a highly desirable practice, because it serves as a water-conservation measure. Waste constituents may thus be concentrated into one waste stream for treatment. In other cases, however, this practice results in the necessity for discharge from a mill-water impoundment system because, even with recycle of part of the process water, a net positive water balance results.

At several sites visited as part of this study, degradation of the mine water quality is caused by combining the wastewater streams for treatment at one location. A negative effect results because water with low pollutant loading serves to dilute water of higher pollutant loading. This often results in decreased water-treatment efficiency because concentrated waste streams can often be treated more effectively than dilute waste streams. The mine water in these cases may be treated by relatively simple methods; while the volume of wastewater treated in the mill impoundment system will be reduced, this water will be treated with increased efficiency.

There are also locations where the use of mine water as process water has resulted in an improvement in the ultimate effluent. Choice of the options to segregate or combine wastewater treatment for mines and mills must be made on an individual basis, taking into account the character of the wastewater to be treated (at both the mine and the mill), the water balance in the mine/mill system, local climate, and topography. The ability of a particular operation to meet zero or reduced effluent levels may be dependent upon this decision at each location.

Regrading

Surface mining may often require removal of large amounts of overburden to expose the ores to be exploited. Regrading involves mass movement of material following ore extraction to achieve a more desirable land configuration. Reasons for regrading strip mined land are:

(1) aesthetic improvement of land surface
(2) returning usefulness to land
(3) providing a suitable base for revegetation
(4) burying pollution-forming materials, e.g., heavy metals
(5) reducing erosion and subsequent sedimentation
(6) eliminating landsliding
(7) encouraging natural drainage
(8) eliminating ponding

(9) eliminating hazards such as high cliffs and deep pits
(10) controlling water pollution

Contour regrading is currently the required reclamation technique for many of the nations's active contour and area surface mines. This technique involves regrading a mine to approximate original land contour. It is generally one of the most favored and aesthetically pleasing regrading techniques because the land is returned to its approximate premined state. This technique is also favored because nearly all spoil is placed back in the pit, eliminating oversteepened downslope spoil banks and reducing the size of erodable reclaimed area. Contour regrading facilitates deep burial of pollution-forming materials and minimizes contact time between regraded spoil and surface runoff, thereby reducing erosion and pollution formation.

However, there are also several disadvantages to contour regrading that must be considered. In area and contour stripping, there may be other forms of reclamation that provide land configurations and slopes better suited to the intended uses of the land. This can be particularly true with steepslope contour strips, where large, high walls and steep final spoil slopes limit application of contour regrading. Mining is, therefore, frequently prohibited in such areas, although there may be other regrading techniques that could be effectively utilized. In addition, where extremely thick ore bodies are mined beneath shallow overburden, there may not be sufficient spoil material remaining to return the land to the original contour.

There are several other reclamation techniques of varying effectiveness which have been utilized in both active and abandoned mines. These techniques include terrace, swale, swallow-tail, and Georgia V-ditch, several of which are quite similar in nature. In employing these techniques, the upper high-wall portion is frequently left exposed or backfilled at a steep angle, with the spoil outslope remaining somewhat steeper than the original contour. In all cases, a terrace of some form remains where the original bench was located, and there are provisions for rapidly channeling runoff from the spoil area. Such terraces may permit more effective utilization of surface-mined land in many cases.

Disposal of excess spoil material is frequently a problem where contour backfilling is not practiced. However, the same problem can also occur, although less commonly, where contour regrading is in use. Some types of overburden rock-particularly, tightly packed sandstones--substantially expand in volume when they are blasted and moved. As a result, there may be a large volume of spoil material that cannot be returned to the pit area, even when contour backfilling is employed. To solve this problem, head-of-hollow fill has been used for overburden storage. The extra overburden is placed in narrow, steep-sided hollows in compacted layers 1.2 to 2.4 meters (4 to 8 feet) thick and graded to control surface drainage.

In this regrading and spoil storage technique, natural ground is cleared of woody vegetation, and rock drains are constructed where natural drains exist, except in areas where inundation has occurred. This permits ground water and natural percolation to leave fill areas without saturating the fill, thereby reducing potential landslide and erosion problems. Normally, the face of the fill is terrace graded to minimize erosion of the steep outslope area.

This technique of fill or spoil material deposition has been limited to relatively narrow, steep-sided ravines that can be adequately filled and graded. Design considerations include the total number of acres in the watershed above a proposed head-of-hollow fill, as well as the drainage, slope stability, and prospective land use. Revegetation usually proceeds as soon as erosion and siltation protection have been completed. This technique is avoided in areas where under-drainage materials contain high concentrations of pollutants, since the resultant drainage would require treatment to meet pollution-control requirements.

Erosion Control

Although regrading is the most essential part of surface-mine reclamation, it cannot be considered a total reclamation technique. There are many other facets of surface-mine reclamation that are equally important in achieving successful reclamation. The effectivenesses of regrading and other control techniques are interdependent. Failure of any phase could severly reduce the effectiveness of an entire reclamation project.

The most important auxiliary reclamation procedures employed at regraded surface mines or refuse areas are water diversion and erosion and runoff control. Water diversion involves collection of water before it enters a mine area and conveyance of that water around the mine site, as discussed previously. This procedure decreases erosion and pollution formation. Ditches are usually excavated upslope from a mine site to collect and convey water. Flumes and pipes are used to carry water down steep slopes or across regraded areas. Riprap and dumped rock are sometimes used to reduce water velocity in the conveyance system.

Diversion and conveyance systems are designed to accommodate predicted water volumes and velocities. If the capacity of a ditch is exceeded, water erodes the sides and renders the ditch ineffective.

Water diversion is also employed as an actual part of the mining procedure. Drainways at the bases of high walls intercept and divert discharging ground water prior to its contact with pollution-forming materials. In some instances, ground water above the mine site is pumped out before it enters the mine area, where it would become polluted and require treatment. Soil erosion is significantly reduced on regraded areas by controlling the course of surface-water runoff, using interception channels constructed on the regraded surface.

There are a large number of techniques in use for controlling runoff, with highly variable costs and degrees of effectiveness. Mulching is sometimes used as a temporary measure which protects the runoff surface from raindrop impacts and reduces the velocity of surface runoff.

Velocity reduction is a critical facet of runoff control. This is accomplished through slope reduction by terracing or grading; revegetation; or use of flow impediments such as dikes, contour plowing, and dumped rock. Surface stabilizers have been utilized on the surface to temporarily reduce erodability of the material itself, but expense has restricted use of such materials in the past.

Revegetation

Establishment of good vegetative cover on a mine area is probably the most effective method of controlling runoff and erosion. A critical factor in mine revegetation is the quality of the soil or spoil material on the surface of a regraded mine. There are several methods by which the nature of this material has been controlled. Topsoil segregation during stripping is mandatory in many states.

This permits topsoil to be replaced on a regraded surface prior to revegetation. However, in many forested, steep-sloped areas, there is little or no topsoil on the undisturbed land surface. In such areas, overburden material is segregated in a manner that will allow the most toxic materials to be placed at the base of the regraded mine, and the best spoil material is placed on the mine surface.

Vegetative cover provides effective erosion control; contributes significantly to chemical pollution control; results in aesthetic improvement; and can return land to agricultural, recreational, or silvicultural usefulness. A dense ground cover stabilizes the surface (with its root system), reduces velocity of surface runoff, helps build humus on the surface, and can virtually eliminate erosion. A soil profile begins to form, followed by a complete soil ecosystem. This soil profile acts as an oxygen barrier, reducing the amount of oxygen reaching underlying materials. This, in turn, reduces oxidation, which is a major contributing factor to pollutant formation.

The soil profile also tends to act as a sponge that retains water near the surface, as opposed to the original loose spoil (which allowed rapid infiltration). This water evaporates from the mine surface, cooling it and enhancing vegetative growth. Evaporated water also bypasses toxic materials underlying the soil, decreasing pollution production. The vegetation itself also utilizes large quantities of water in its life processes and transpires it back to the atmosphere, again reducing the amount of water reaching underlying materials.

Establishment of an adequate vegetative cover at a mine site is dependent on a number of related factors. The regraded surface of many spoils cannot support a good vegetative cover without supplemental treatment. The surface texture is often too irregular, requiring the use of raking to remove as much rock as possible and to decrease the average grain size of the remaining material. Materials toxic to plant life, usually buried during regrading, generally do not appear on or near the final graded surface. If the surface is compacted, it is usually loosened by discing, plowing, or roto-tilling prior to seeding in order to enhance plant growth.

Soil supplements are often required to establish a good vegetative cover on surface-mined lands and refuse piles, which are generally deficient in nutrients. Mine spoils are often acidic, and lime must be added to adjust the pH to the tolerance range of the species to be planted. It may be necessary to apply additional neutralizing material to revegetated areas for some time to offset continued pollutant generation.

Several potentially effective soil supplements are currently undergoing research and experimentation. Flyash is a waste product of coal-fired boilers and resembles soil with respect to certain physical and chemical properties. Flyash is often alkaline, contains some plant nutrients, and possesses moistureretaining and soil-conditioning capabilities. Its main function is that of an alkalinity source and a soil conditioner, although it must usually be augmented with lime and fertilizers. However, flyash can vary drastically in quality--particularly, with respect to pH--and may contain leachable materials capable of producing water pollution. Future research, demonstration, and monitoring of flyash supplements will probably develop the potential use of such materials.

Limestone screenings are also an effective long-term neutralizing agent for acidic spoils. Such spoils generally continue to produce acidity as oxidation continues. Use of lime for direct planting upon these surfaces is effective, but it provides only short-term alkalinity. The lime is usually consumed after several years, and the spoil may return to its acidic condition. Limestone screenings are of larger particle size and should continue to produce alkalinity on a decreasing scale for many years, after which a vegetative cover should be well-established. Use of large quantities of limestone should also add alkalinity to receiving streams. These screenings are often cheaper than lime, providing larger quantities of alkalinity for the same cost. Such applications of limestone are currently being demonstrated in several areas.

Use of digested sewage sludge as a soil supplement also has good possibilities for replacing fertilizer and simultaneously alleviating the problem of sludge disposal. Sewage sludge is currently being utilized for revegetation in strip-mined areas of Ohio. Besides supplying various nutrients, sewage sludge can reduce acidity or alkalinity and effectively increase soil absorption and moisture-retention capabilities. Digested sewage sludge can be applied in liquid or dry form and must be incorporated into the spoil surface. Liquid sludge applications require large holding ponds or tank trucks, from which sludge is pumped and sprayed over the ground, allowed to dry, and disced into the underlying material. Dry sludge application requires dryspreading machinery and must be followed by discing.

Limestone, digested sewage sludge, and flyash are all limited by their availabilities and chemical compositions. Unlike commercial fertilizers, the chemical compositions of these materials may vary greatly, depending on how and where they are produced. Therefore, a nearby supply of these supplements may be useless if it does not contain the nutrients or pH adjusters that are deficient in the area of intended application. Flyash, digested sewage sludge, and limestone screenings are all waste products of other processes and are, therefore, usually inexpensive. The major expense related to utilization of any of these wastes is the cost of transporting and applying the material to the mine area. Application may be quite costly and must be uniform to effect complete and even revegetation.

When such large amounts of certain chemical nutrients are utilized, it may also be necessary to institute controls to prevent chemical pollution of adjacent waterways. Nutrient controls may consist of preselection of vegetation to absorb certain chemicals, or of construction of berms and retention basins in which runoff can be collected and sampled, after which it can be discharged or pumped back to the spoil. The specific soil supplements and application rates employed are selected to provide the best possible conditions for the vegetative species that are to be planted.

Careful consideration should be given to species selection in surface-mine reclamation. Species are selected according to some land-use plan, based upon the degree of pollution control to be achieved and the site environment. A dense ground cover of grasses and legumes is generally planted, in addition to tree seedlings, to rapidly check erosion and siltation. Trees are frequently planted in areas of poor slope stability to help control landsliding. Intended future use of the land is an important consideration with respect to species selection. Reclaimed surface-mined lands are occasionally returned to high-use categories, such as agriculture, if the land has potential for growing crops. However, when toxic spoils are encountered, agricultural potential is greatly reduced, and only a few species will grow.

Environmental conditions--particularly, climate--are important in species selection. Usually, species are planted that are native to an area--particularly, species that have been successfully established on nearby mine areas with similar climate and spoil conditions.

Revegetation of arid and semi-arid areas involves special consideration because of the extreme difficulty of establishing vegetation. Lack of rainfall and effects of surface disturbance create hostile growth conditions. Because mining in arid regions has only recently been initiated on a large scale, there is no standard revegetation technology. Experimentation and demonstration projects exploring two general revegetation techniques--moisture retention and irrigation--are currently being conducted to solve this problem.

Moisture retention utilizes entrapment, concentration, and preservation of water within a soil structure to support vegetation. This may be obtained utilizing snow fences, mulches, pits, and other methods.

Irrigation can be achieved by pumping or by gravity, through either pipes or ditches. This technique can be extremely expensive, and acquisition of water rights may present a major problem. Use of these arid-climate revegetation techniques in conjunction with careful overburden segregation and regrading should permit return of arid mined areas to their natural states.

Exploration, Development, and Pilot-Scale Operations

Exploration activities commonly employ drilling, blasting, excavation, tunneling, and other techniques to discover, locate, or define the extent of an ore body. These activities vary from small-scale (such as a single drill hole) to large-scale (such as excavation of an open pit or outcrop face). Such activities frequently contribute to the pollutant loading in wastewater emanating from the site. Since available facilities (such as power sources) and ready accessibility of special equipment and supplies often are limited, sophisticated treatment is often not possible. In cases where exploration activity is being carried out, the scale of such operations is such that primary water-quality problems involve the presence of increased suspended-solid loads and potentially severe pH changes. Ponds should be provided for settling and retention of wastewater, drilling fluids, or runoff from the site. Simple, accurate field tests for pH can be made, with subsequent pH adjustment by addition of lime (or other neutralizing agents).

Protection of receiving waters will thus be accomplished, with the possible additional benefits of removal of metals from solution--either in connection with solids removal or by precipitation from solution.

Development operations frequently are large-scale, compared to exploration activities, because they are intended to extend already known or currently exploited resources. Because these operations are associated with facilities and equipment already in existence, it is necessary to plan development activities to minimize pollution potential, and to use existing mine or mill treatment and control methods and facilities. These operations should, therefore, be subject to limitations equivalent to existing operations with respect to effluent treatment and control.

Pilot-scale operations often involve small to relatively large mining and beneficiation facilities even though they may not be currently operating at full capacity or are in the process of development to full-scale. Planning of such operations should be undertaken with treatment and control of wastewater in mind to ensure that effluent limitation guidelines and standards of performance for the category or subcategory will be met. Although total loadings from such operations and facilites are not at the levels expected from normal operating conditions, the compositions of wastes and the concentrations of wastewater parameters are likely to be similar. Therefore, implementation of recommended treatment and control technologies must be accomplished.

Mine and Mill Closure

Mine Closure (Underground). Unless well-planned and well-designed abatement techniques are implemented, an underground mine can be a permanent source of water pollution.

Responsibility for the prevention of any adverse environmental impacts from the temporary or permanent closure of a deep mine should rest solely and permanently with the mine operator. This constitutes a substantial burden; therefore, it behooves the operator to make use of the best technology available for dealing with pollution problems associated with mine closure. The two techniques most frequently utilized in deep-mine pollution abatement are treatment and mine sealing. Treatment technology is well defined and is generally capable of producing acceptable mine effluent quality. If the mine operator chooses this course, he is faced with the prospect of costly permanent treatment of each mine discharge.

Mine sealing is an attractive alternative to the prospects of perpetual treatment. Mine sealing requires the mine operator to consider barrier and ceiling-support design from the perspectives of strength, mine safety, their ability to withstand high water pressure, and their utility for retarding groundwater infiltration. In the case of new mines, these considerations should be included in the mine design to cover the eventual mine closure. In the case of existing mines, these considerations should be evaluated for existing mine barriers and ceiling supports, and the future mine plan should be adjusted to include these considerations if mine sealing is to be employed at mine closure.

Sealing eliminates the mine discharge and inundates the mine workings, thereby reducing or terminating the production of pollutants. However, the possibility of the failure of mine seals or outcrop barriers increases with time as the sealed mine workings gradually became inundated by ground water and the hydraulic head increases. Depending upon the rate of ground-water influx and the size of the mined area, complete inundation of a sealed mine may require several decades. Consequently, the maximum anticipated hydraulic head on the mine seals may not be realized for that length of time. In addition, seepage through, or failure of, the barrier or mine seal could occur at any time. Therefore, the mine operator should be required to permanently maintain the seals, or to provide treatment in the event of seepage or failure.

Mine Closure (Surface). The objectives of proper reclamation management of closed surface mines and associated workings are to (1) restore the affected lands to a condition at least fully capable of supporting the uses which they were capable of supporting prior to any mining, and (2) achieve a stability which does not pose any threat to public health, safety, or water pollution. With proper planning and management during mining activities, it is often possible to minimize the amount of land disturbed or excavated at any one time. In preparation for the day the operation may cease, a reclamation schedule for restoration of existing affected areas, as well as those which will be affected, should be specified. The use of a planned methodology such as this will return the workings to their premined condition at a faster rate, as well as possibly reduce the ultimate costs to the operator.

To accomplish the objectives of the desired reclamation goals, it is mandatory that the surface-mine operator regrade and revegetate the disturbed area during, or upon completion of, mining. The final regraded surface configuration is dependent upon the ultimate land use of the specific site, and control practices described in this report can be incorporated into the regrading plan to minimize erosion and sedimentation. The operator should establish a diverse and permanent vegetative cover and a plant succession at least equal in extent of cover to the natural vegetation of the area. To assure compliance with these requirements and permanence of vegetative cover, the operator should be held responsible for successful revegetation and effluent water quality for a period of five full years after the last year of augmented seeding. In areas of the country where the annual average precipitation is 64 cm (26 in.) or less, the operator's assumption of responsibility and liability should extend for a period of ten full years after the last year of augmented seeding, fertilization, irrigation, or effluent treatment (Reference 30).

Mill Closure. As with closed mines, a beneficiation facility's potential contributions to water pollution do not cease upon shutdown of the facility. Tailing ponds, waste or refuse piles, haulage areas, workings, dumps, storage areas, and processing and shipping areas often present serious problems with respect to contributions to water pollution. Among the most important are tailing ponds, waste piles, and dump areas. Since no wastewater is contributed from the processing of ores (the facility being closed), the ponds will gradually become dewatered by evaporation or by percolation into the subsurface. The structural integrity of the tailing-pond walls should be periodically examined and, if necessary, repairs made. Seeding and vegetation can assist in stabilizing the walls, prevent erosion and sedimentation, lessen the probability of structural failure, and improve the aesthetics of the area.

Refuse, waste, and tailing piles should be recontoured and revegetated to return the topography as near as possible to the condition it was in before the activity. Techniques employed in surface-mine regrading and revegetation should be utilized. Where mills are located adjacent to mine workings, the mines can be refilled with tailings. Care should be taken to minimize disruption of local drainage and to ensure that erosion and sedimentation will not result. Studies have indicated that to insure success of revegatation efforts, maintenance of such refuse or waste piles and tailing-disposal areas should be performed for at least five years after the last year of regrading and augmented seeding. In areas of the country where the annual average precipitation is 64 cm (26 in.) or less, maintenance should extend for a period of ten full years after the last year of augmented seeding, fertilization, irrigation, or effluent treatment (Reference 30).

TREATMENT TECHNOLOGY

Each of the techniques currently employed in the ore mining and dressing industry, as well as advanced waste treatment technology which might be employed in present or future operations, is discussed in this section.

The treatment technologies currently practiced in the ore mining and dressing industry encompass a wide variety of techniques ranging from the very simple to the highly sophisticated. While a limited number of basic treatment practices are standard (settling or tailing ponds, pH control, etc.) and employed at almost all operations, individual operations have approached specific pollution problems in many different ways.

Impoundment Systems

This group of systems utilizes treatment technology which is primarily designed to deal with suspended solids, but which is frequently used with such other techniques as pH control, to accomplish removal of dissolved constituents as well.

Tailing Ponds. This type of treatment is the most common treatment technique used in the ore mining and dressing industry today. The design of a tailing pond is primarily for suspended solid removal and retention. Such a pond must be large enough to provide sufficient retention time and quiescent conditions conducive to settling. If properly designed, and if retention time and surface area are sufficient, a tailing pond may also effect to some degree the stabilization of oxidizable constituents as well as the balancing of influent quality and quantity fluctuations and the storage of storm water.

Tailing ponds are often situated to capitalize upon natural terrain factors in order to minimize the requirements for dam construction. The containment dam is often constructed of available earth and rock materials, as well as tailings. In other cases, concrete basins may be constructed. Because of natural terrain conditions, they may be constructed using one, two, three, or even four walls. The containment dam must be raised periodically to accommodate the rising level of contained tailings and water. In most cases, the basin provides perpetual storage for any materials settled out of the water treated. Retention time in ponds has been reported to vary from as little as four hours to as much as several months at average flow conditions (for discharging systems).

Water leaves a tailing pond by decantation, evaporation, seepage through the dam or to underlying materials, or by discharge. Decanted water may be recycled for use in the mill, discharged, or treated further. In some operations, in arid or semi-arid areas, evaporation from the tailing-pond surface may equal the rate of input, allowing zero-discharge operation of the pond without recycle of water.

Seepage losses from tailing ponds may flow into permeable underlying strata and enter ground water, or may flow through the containment dam and result in surface flows of water. Seepage waters are often collected in ditches and pumped back into the tailing pond. Seepage may also be limited by the use of pond liners of various materials (clay, asphalt, plastic, etc.).

Low-cost, relatively simple construction and the ability to perform multiple functions simultaneously have led to the wide acceptance of tailing ponds as a prime treatment and tailing-disposal method utilized by the ore mining and dressing industry. There are a number of problems associated with the utilization of tailing ponds as treatment facilities, however. Improper design of inlet and discharge locations, insufficient size and number, and insufficient retention time are the most common problems. Algal growths in tailing ponds are quite common during warm months, a factor which may influence such effluent water-quality parameters as TOC, COD, TSS, and BOD. A minimum retention time of 30 days and the added capability of retaining runoff associated with a storm likely to occur once in 20 years are recommended by one source (Reference 31).

The relative advantages and disadvantages of a tailing pond as a treatment system are listed below.

Advantages	Disadvantages
Performs large number of treatment processes--particularly, suspended-solid removal.	Lacks responsive means of control; difficult to optimize large number of processes performed.
Can achieve high treatment efficiency and often produce acceptable effluent quality.	Covers large surface area--may contribute high net precipitation to overall water balance; land availability and topography influence location.
Often, only practical means of long-term solids disposal	Creates potentially severe rehabilitation problem if tailings contain sulfide minerals.
Large retention has a balancing effect on effluent quality.	Often difficult to isolate from contributing drainage areas--storm water influences retention.
Large surface area aids oxidation and evaporation.	Subject to climatic variations--particularly, thermal skimming and seasonal variation in bio-oxidation efficiency.
Can often be constructed using mining equipment and materials.	Often difficult to ensure good flow distribution.
Little operating expertise normally required.	Requires careful control of seepage through dams.
Commonly used treatment method, familiar to industry.	Installation expensive in some situations, due to high cost of retaining structures.
Clear supernatant water may serve as a reservoir for reuse.	

Tailing ponds in the ore mining and dressing industry range from pits to large, engineered structures of 1000 acres or more with massive retaining dams. For large tailing dams, wall heights of 61 meters (200 feet) or more have been reached by building up the dams over a period of time.

Routinely reached levels of suspended-solid concentrations in treated effluent range from 10 to 30 mg/l at mines and mills visited or surveyed as part of this study. In tailing ponds with decant structures for recycle of water, levels in excess of 50 mg/l of suspended solids were rarely observed.

Settling Ponds. Settling ponds differ from tailing ponds primarily in size and in the concentrations of influent solids treated. In general, relatively low initial solid loads are removed, necessitating only occasional dredging to maintain adequate settling volume behind the dam. Suspended-solid removal to very low levels is often possible when initial concentrations of suspended solids are low. Settling ponds find their greatest usefulness in association with mines having low wastewater solids loads.

Such ponds may serve a variety of purposes in addition to removal of suspended solids, including COD reduction and cooling. As basins for a variety of chemical treatments, they can provide sufficient retention time for completion of reactions, for pH control, for chemical precipitation, and for the removal of solids produced.

Secondary Settling Ponds. Settling ponds or tailing ponds are frequently used in a multiple arrangement. The purpose of this scheme is to further reduce suspended-solid loading in the sequential ponds and to allow the subsequent use of precipitation or pH control before discharge or recycle. The ponds enable further reduction in suspended solids and in dissolved parameters. An excellent example is the use of secondary settling ponds (sometimes called polishing ponds) in the coprecipitation of radium with barium.

Clarifiers and Thickeners

A method of removing large amounts of suspended solids from wastewater is the use of clarifiers or thickeners, which are essentially large tanks with directing and segregating systems. The design of these devices provides for concentration and removal of suspended and settleable solids in one effluent stream and a clarified liquid in the other. Clarified waters may be produced which have extremely low solids content through proper design and application.

Clarifiers are not generally capable of handling tailing-solid levels above about 50 percent, due to the necessity for rake operation and hydraulic transport of suspended solids from the device. The concentration from a mine-water clarifier at one site, for example, was observed to be 3 mg/l suspended solids.

Clarifiers may range in design from simple units to more complex systems involving sludge blanket pulsing or sludge recycle to improve settling and increase the density of the sludge. Settled solids from clarifiers are removed periodically or continuously for either disposal or recovery of contained values. Thickeners are used when the main purpose is to produce a clarified overflow with a concentrated tailing effluent in the underflow.

Thickeners have a number of distinct advantages over settling or tailing ponds:

(1) Less land space is required. Area-for-area, these devices are much more efficient in settling capacity than ponds.

(2) Influences of rainfall are reduced compared to ponds. If desired, the clarifiers and thickeners can be covered.

(3) Since the external construction of clarifiers and thickeners consists of concrete or steel (in the form of tanks), infiltration and rain-water runoff influences do not exist.

(4) Thickeners can generally be placed adjacent to a mill, making reclaim water available nearby with minimal pumping requirements.

The use of clarifiers and thickeners, together with tailing or settling ponds, may improve treatment efficiency; reduce the area needed for tailing ponds; and facilitate the reuse or recycle of water in the milling operation. The use of flocculants to enhance the performance of thickeners and clarifiers is common practice.

Clarifiers and thickeners also suffer some distinct disadvantages compared to ponds:

(1) They have mechanical parts and, thus, require maintenance.

(2) They have limited storage capacity for either clarified water or settled solids.

(3) The internal sweeps and agitators in thickeners and clarifiers require more power and energy for operation than ponds.

Flocculation

This treatment process consists basically of adding reagents to the treated waste stream to promote settling of suspended solids. The solids may be deposited in tailing ponds (where high suspended solids are involved) or in settling ponds or clarifier tanks (in cases of lower solids loads).

Flocculating agents increase the efficiency of settling facilities and are of several general types: ferric compounds, lime, aluminum sulfate, and cationic or anionic polyelectrolytes. Causticized wheat and corn starch have also been used. The ionic types, such as alum, ferrous sulfate, lime, and ferric chloride, function by destroying the repelling double-layer ionic charges around the suspended particles and thereby allowing the particles to attract each other and agglomerate. Polymeric types function by forming physical bridges from one particle to another and thereby agglomerating the particles. Recyclable magnesium carbonate has also been proposed as a flocculant in domestic water treatment.

Flocculating agents are added to the water to be treated under controlled conditions of concentration, pH, mixing time, and temperature. They act to upset the stability of the colloidal suspension by charge neutralization and flocculation of suspended solids, thus increasing the effective diameter of these solids and increasing their subsequent settling rate.

Flocculating agents are most commonly used after the larger, more readily settled particles (and loads) have been removed by a settling pond, hydrocyclone, or other treatment. Agglomeration, or flocculation, can then be achieved with less reagent, and with less settling load on the polishing pond or clarifier.

Flocculation agents can be used with minor modifications and additions to existing treatment systems, but the costs for the flocculating chemicals are often significant. Ionic types are used in concentrations of 10 to 100 mg/l in the wastewater, while the highest-priced polymeric types are effective in concentrations of 2 to 20 mg/l.

The effectiveness and performance of individual flocculating systems may vary over a substantial range with respect to suspended-solid removal, accessory removal of soluble components by adsorptive phenomena, and operating characteristics and costs. Specific system performance must be analyzed and optimized with respect to mixing time, flocculant addition level, settling (detention) time, thermal and wind-induced mixing, and other factors.

Centrifugation

Centrifugation, which may be considered as a form of forced or assisted settling, may be feasible in specific control applications. With the volume of gross wastewater flows at most mine/mill complexes, it is probable that centrifugation may be more applicable to component in-process waste streams. The presence of abrasive components or significant amounts of solid material smaller than approximately 5 micrometers in diameter in the treated water would tend to disqualify centrifugation as a solid-removal option.

Hydrocyclones

While hydrocyclones are widely used in the separation, classification, and recovery operations involved in mineral processing, they are used only infrequently for wastewater treatment. Even the smallest-diameter units available (stream-velocity and centrifugal-separation forces both increase as the diameter decreases) are ineffective when particle size is less than 25 to 50 micrometers. Larger particle sizes are relatively easy to settle by means of small ponds, thickeners or clarifiers, or other gravity-principle settling devices. It is the smaller suspended particles that are the most difficult to remove, and it is these that cannot be removed by hydrocyclones but may be handled by ponds or other settling technology. Also, hydrocyclones are of doubtful effectiveness when flocculating agents are used to increase settling rates. This method is generally most effective in the 25- to 200-micrometer size range for particles.

Filtration

Filtration is accomplished by passing the wastewater stream through solid-retaining screens or cloths or particulate materials such as sand, gravel, coal, or diatomaceous earth using gravity, pressure, or vacuum as the driving force. Filtration is a versatile method in that it can be used to remove a wide range of suspended particle sizes.

A variety of filtration techniques, including disc and drum units, find process applications and may be applicable to some waste streams--particularly, where segregated waste streams require special treatment.

Likely applications of filtration include pretreatment of input streams using reverse-osmosis and ion-exchange units (discussed later).

High values contained in suspended solids may, in some cases, offset the capital and operating expenses of filtering systems. The use of filtration as a normal unit process in treating uranium-mill tailings for value recovery through countercurrent washing is indicative of the possible use of filtration in tailing treatment. In this instance, the final washed tail filter cake is reslurried for transport to the tailing pond. In situations where biological treatment of component or combined waste streams is required to reduce BOD, COD, or bacterial loads, trickling filters may be required, but their application as primary treatment for the bulk mine or mill effluent is considered unlikely.

The specific applicability and size specifications for filter modules must be evaluated on a case-by-case basis, taking into account the process stream characteristics, solids filterability, desired dryness of filter cake, and other parameters.

Ultimate clarification of filtered water will be a function of particle size, filter-media porosity, filtration rate, and other variables. In general, for the majority of mine or mill wastewaters subjected to this treatment, post-treatment suspended-solid levels of less than 20 percent of influent loadings are anticipated. Thus, if used after primary flocculation and settling, suspended solids levels of 20 mg/l should be obtainable.

Neutralization

Adjustment of pH is the simplest and most common chemical treatment practiced in the mining and milling industry today. The addition of either acidic or basic constituents to a wastewater stream to achieve neutralization generally influences the behavior of both suspended and dissolved components. In most instances of interest in mining and milling activities, wastewater is treated by base addition to achieve pH conditions in the range of 6 to 9.

Acid waste streams (considerably more common than highly basic effluents) may be neutralized by addition of a variety of basic reagents, including lime (calcium oxide), limestone, dolomite ($CaMg(CO_3)_2$), magnesite ($MgCO_3$), sodium hydroxide, soda ash (sodium carbonate), ammonium hydroxide, and others to raise the pH of treated waste streams to the desired level. Lime is most often used because it is inexpensive and easy to apply. Soda ash and caustic soda are commonly used to supply alkalinity in leaching and hydrometallurgical processes, where the formation of calcium precipitates would be objectionable, but the cost advantages of using lime generally preclude the use of soda ash and caustic soda in large-scale waste treatment.

Ammonia neutralization is most frequently a processing technique, where ammonia affords a strong advantage in being volatile in the final product, allowing the recovery of nearly pure oxides. In waste treatment, its volatility is a disadvantage. Because of the COD it presents, its toxicity, and the production of undesirable nitrites and nitrates as oxidation products, its use is not widespread, although ammonia neutralization of a wastewater stream is practiced at one site in the ferroalloy ore mining and milling category.

Excessively basic waste streams are not common but may be neutralized by addition of an acid--most commonly, sulfuric. Since many heavy metals form insoluble hydroxides in highly basic solutions, sedimentation prior to neutralization may prevent the resolubilization of these materials and may simplify subsequent waste-treatment requirements. Carbon dioxide has also been used to adjust the pH of effluent waters to acceptable levels prior to discharge (recarbonation).

Essentially any wastewater stream may be treated to a final pH within the range of 6 to 9. Generally, the stream will be sufficiently uniform to allow adequate pH control based only on the volume of flow and predetermined dosage rates, with periodic adjustments based on effluent pH. Automated systems which monitor and continously adjust the concentration of reagents added to the wastewater are also currently available.

As discussed previously, pH control is often used to control solubility (also discussed under Chemical Precipitation Processes). Examples of pH control being used for precipitating undesired pollutants are:

(1) $Fe(+3) + 3OH(-) \longrightarrow Fe(OH)_3$

(2) $Mn(+2) + 2OH(-) \longrightarrow Mn(OH)_2$

(3) $Zn(+2) + OH(-) \longrightarrow Zn(OH)_2$

(4) $Pb(+2) + 2OH- \longrightarrow Pb(OH)_2$

(5) $Cu + 2OH(-) \longrightarrow Cu(OH)_2$

Reaction (1) is used for removal of iron contaminants. Reaction (2) is used for removal of manganese from manganese-containing wastewater. Reactions (3), (4), and (5) are used on wastewater containing copper, lead, and zinc salts. The use of lime to attain a pH of 7 will theoretically reduce heavy metals to these levels (Reference 32):

Metal	Concentration (mg/l at pH 7)
Cu(+2)	0.2 to 0.3
Zn(+2)	1.0 to 2.5
Cd(+2)	1.0
Ni(+2)	1.0
Cr(+2)	0.4

The careful control of pH, therefore, has other ancillary benefits, as illustrated above. The use of pH and solubility relationships to improve removal of wastewater contaminants is further developed below.

Chemical Precipitation Processes

The removal of materials from solution by the addition of chemicals which form insoluble (or sparingly soluble) compounds with them is a common practice in hydrometallurgical ore beneficiation and in waste treatment in the ore mining and dressing industry. It is especially useful for the removal of heavy metals from mine effluents and process wastes.

To be successful, direct precipitation depends primarily upon two factors:

(1) Achievement of a sufficient excess of the added ion to drive the precipitation reaction to completion.

(2) Removal of the resulting solids from the waste stream.

If the first requirement is not met, only a portion of the pollutant(s) will be removed from solution, and desired effluent levels may not be achieved. Failure to remove the precipitates formed prior to discharge is likely to lead to redissolution, since ionic equilibria in the receiving stream will not, in general, be those created in treatment. Effective sedimentation or filtration is, thus, a vital component of a precipitation treatment system and frequently limits the overall removal efficiency. Sedimentation may be effected in the tailing basin itself, in secondary or auxiliary settling ponds, or in clarifiers. Industry experience has shown the value of treatment of wastes prior to delivery to the tailing impoundment. Benefits derived include: improved settling of precipitates due to interaction with tailings; simplified disposal of sludges; and, generally, suppressed solubility of materials in tailing solids.

The use of precipitation for wastewater treatment varies from lime treatments (to precipitate sulfates, fluorides, hydroxides, and carbonates) to sodium sulfide precipitation of copper, lead, and other toxic heavy metals. The following equations are examples of precipitation reactions used for wastewater treatment:

(1) $Fe(+3) + Ca(OH)_2 \longrightarrow Ca(+2) + Fe(OH)_3$

(2) $Mn(+2) + Ca(OH)_2 \longrightarrow Ca(+2) + Mn(OH)_2$

(3) $Zn(+2) + Na_2CO_3 \longrightarrow Na(+) + ZnCO_3$

(4) $SO_4(-2) + Ca(OH)_2 \longrightarrow CaSO_4 + 2OH(-)$

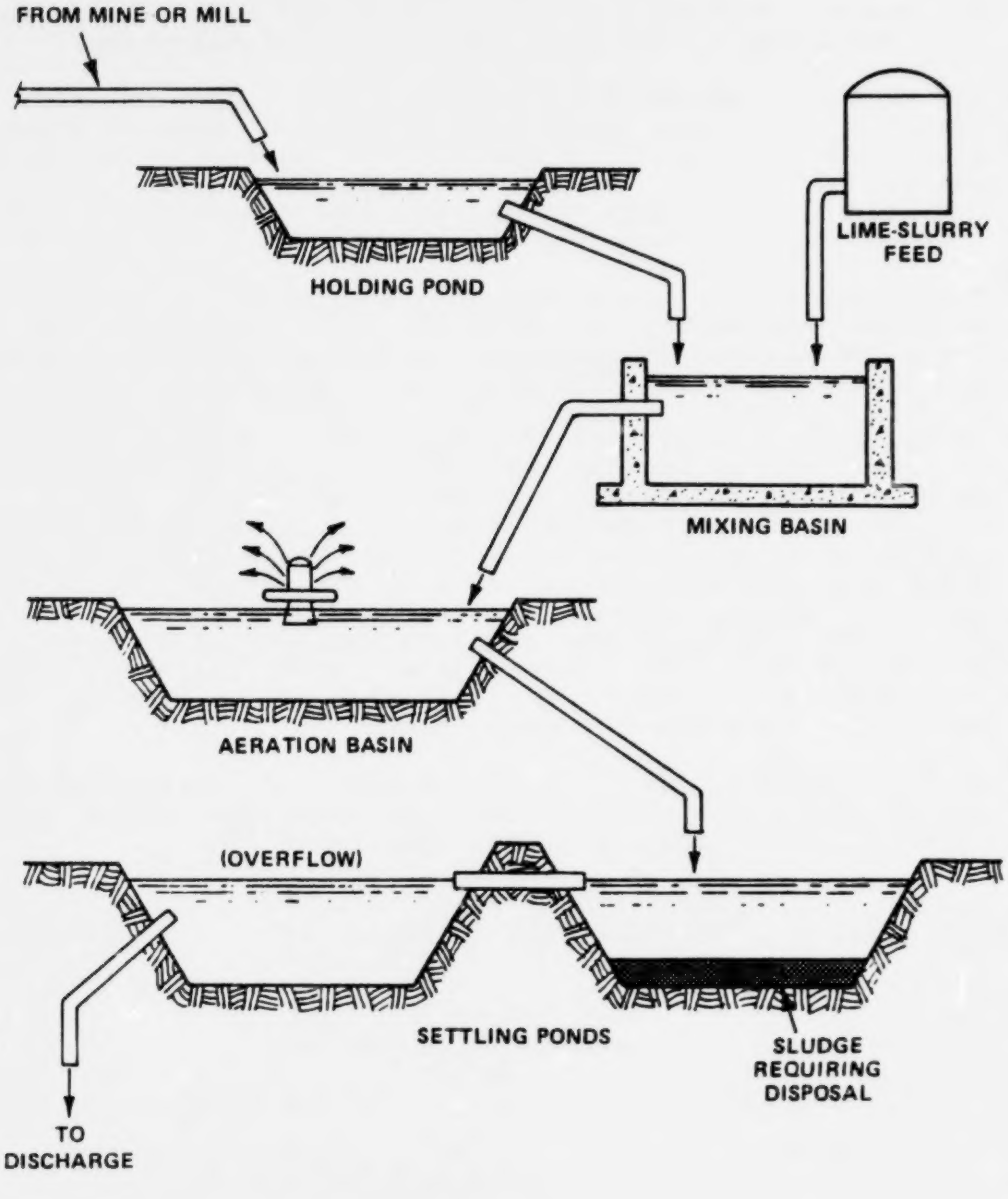
(5) $2F(-) + Ca(OH)2 \longrightarrow CaF_2 + 2OH(-)$

One drawback of the precipitation reactions is that of varying solubility and unknown interactions of several metal compounds, and the possibility of widely divergent formation and precipitation rates, limit the ability of this treatment to deal with all waste constituents.

Lime Precipitation. The use of lime to cause chemical precipitation has gained widespread use in the ore mining and dressing industry because of its ease of handling, because of its economy, and because of its effectiveness in treatment of a great variety of dissolved materials. The use of other bases is, of course, possible, as previously discussed. However, the use of lime as a treatment reagent is probably the best-known and best-studied method.

A typical lime neutralization/precipitation system is illustrated in Figure VII-1. Generally, water is pumped or discharged to a holding or settling pond, where suspended-solid levels are reduced. Either in conjunction with the

Figure VII-1. LIME NEUTRALIZATION AND PRECIPITATION PROCESS FOR TREATMENT OF MINE WATER PRIOR TO DISCHARGE


FROM MINE OR MILL
HOLDING POND
LIME-SLURRY FEED
MIXING BASIN
AERATION BASIN
(OVERFLOW)
SETTLING PONDS
SLUDGE REQUIRING DISPOSAL
TO DISCHARGE

SOURCE: Reference 33

primary pond itself or in a mixing basin or tank, a slurry of lime and water is delivered for mixing with the wastewater stream. Secondary settling ponds are then used to collect the usually high volumes of sludges which may be recovered. These impoundments may be dredged periodically to remove sludges, or the sides of the basin may be built up. Discharge of the water then usually takes place.

The treatment conditions, dosages, and final pH must be optimized for any given waste stream, but, in general, attainment of a pH of at least 9 is necessary to ensure removal of heavy metals. To attain desired levels of control for many heavy metals, it is necessary to attain a pH of 10 to 12 in many instances (refer to Figure VII-3).

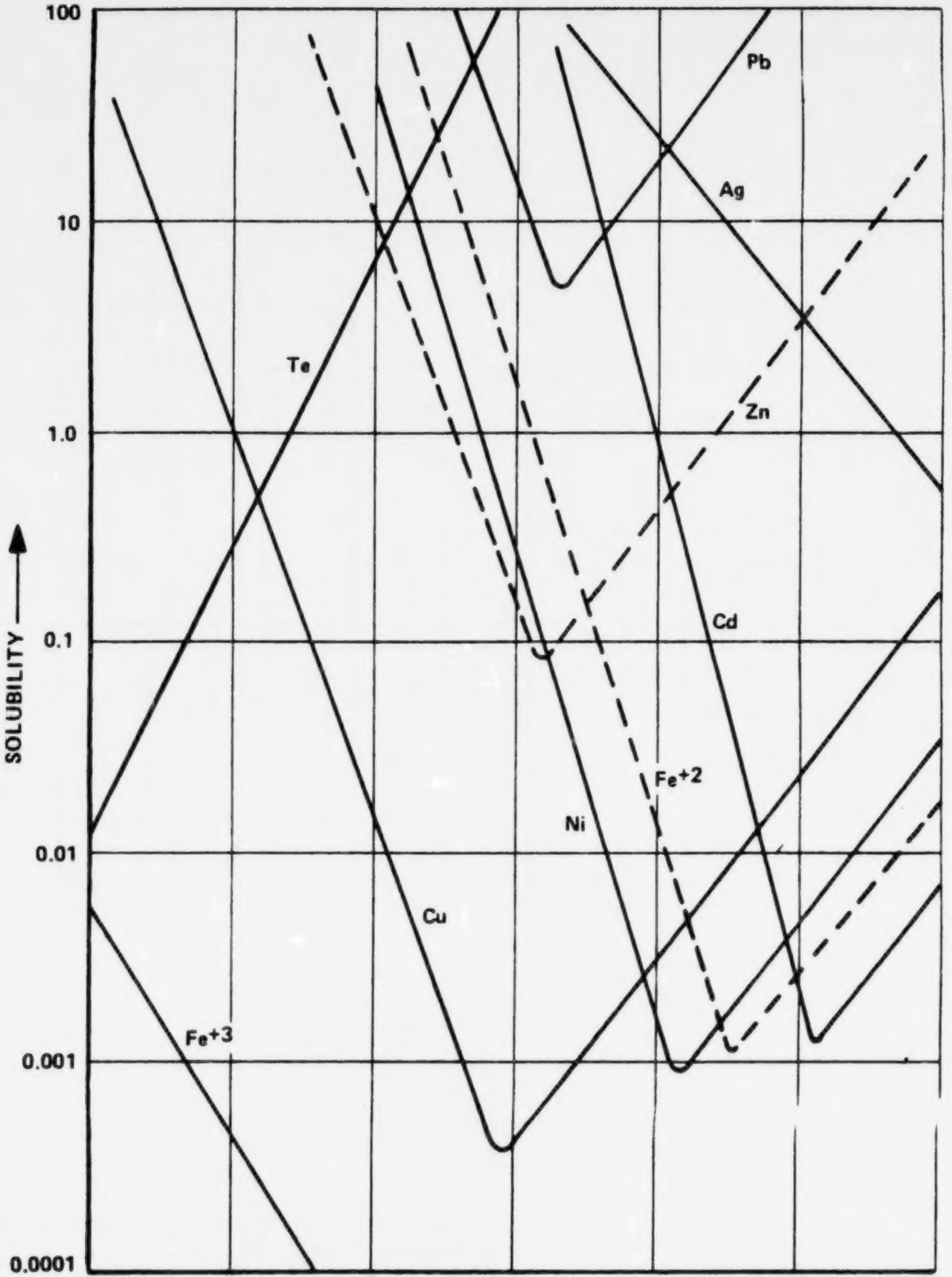
The levels of concentration attainable in an actual operating system may vary from the limits predicted on the basis of purely theoretical considerations, but extremely low levels of metals discharged have been reached by the use of this treatment method. Figure VII-2 illustrates the theoretical solubilities of several metal ions as a function of pH. The minimum pH value for complete precipitation of metal ions as hydroxides is shown in Figure VII-3. An example of the performance of lime precipitation at elevated pH is given for Fe, Pb, Zn, Cd, Hg, and F in Figure VII-4. These data are taken from a combination zinc plant/lead smelter, where removal efficiency is plotted against pH. The curves are not always complete for lack of data; it is not advisable to extrapolate them without further measurements, because chemical changes may occur that reverse an apparent consistent trend.

Purely theoretical considerations of metal-hydroxide solubility relationships suggest that the metal levels tabulated below are attainable (Reference 31).

Metal	Final Concentration (microgram per liter)	pH
Cu(+2)	1 to 8	9.5
Zn(+2)	10 to 60	10
Pb	1	8
Fe(total)	1	8 (if totally Ferric)

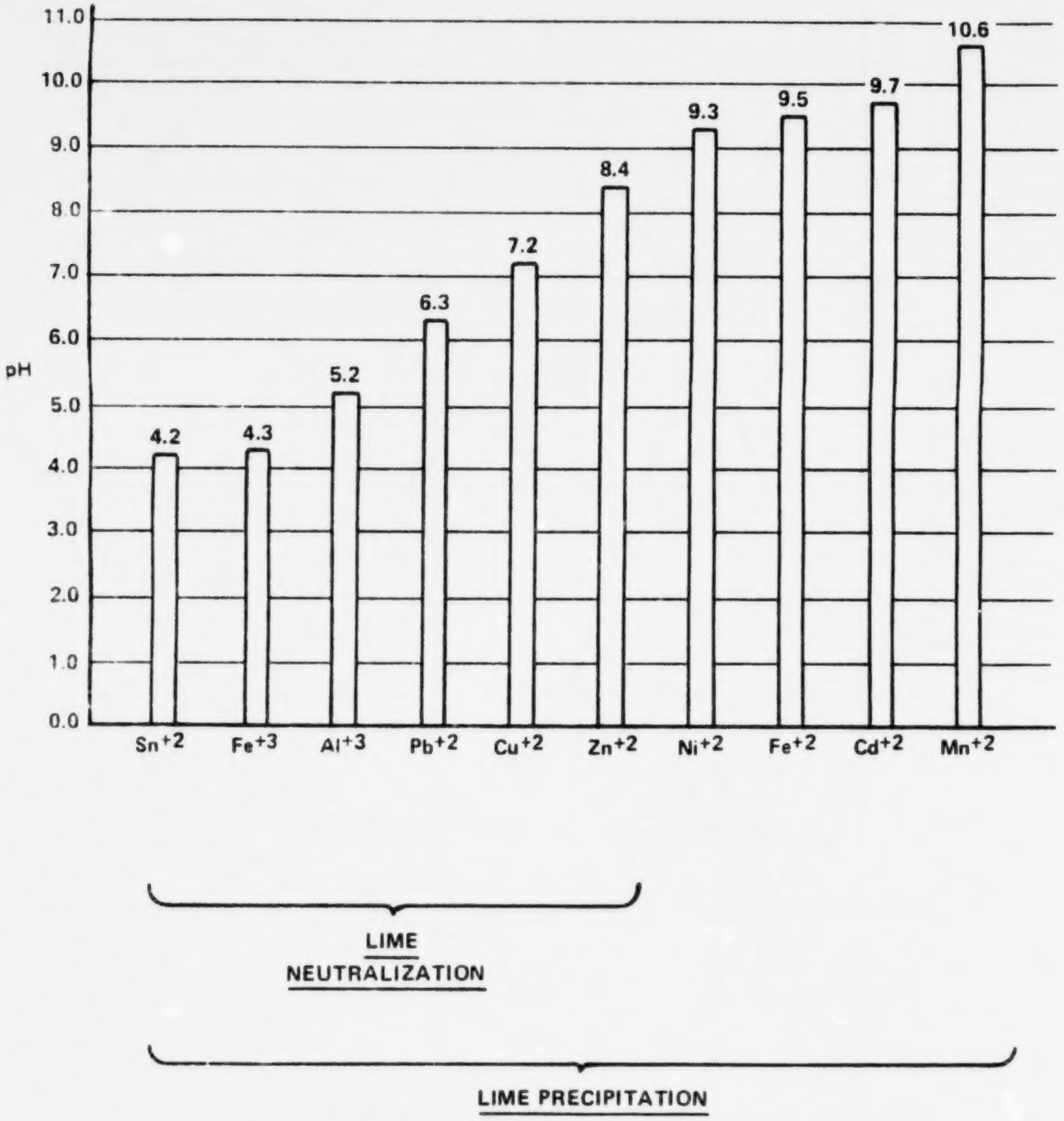
Many factors, such as the effects of widely differing solubility products, mixed-metal hydroxide complexing, and metal

Figure VII-2. THE RELATIONSHIP OF THEORETICAL SOLUBILITIES OF METAL IONS AS A FUNCTION OF pH



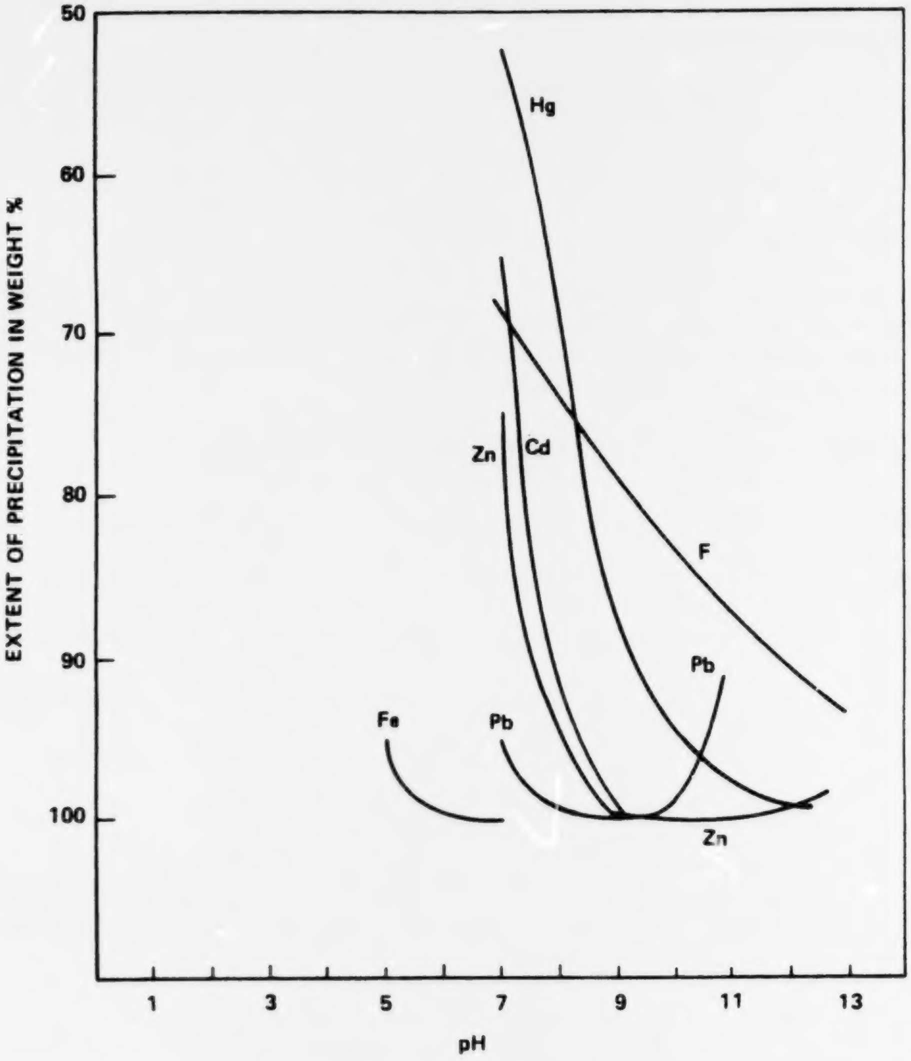
SOURCE: Adapted from Reference 34

Figure VII-3. MINIMUM pH VALUE FOR COMPLETE PRECIPITATION OF METAL IONS AS HYDROXIDES



SOURCE: Reference 33

Figure VII-4. HEAVY-METAL PRECIPITATION vs pH FOR TAILING-POND EFFLUENT pH ADJUSTMENTS BY LIME ADDITION



SOURCE: Reference 35

chelation, render these levels of only limited value when assessing attainable concentrations in a treatment system.

Among the metals effectively removed at basic pH are: As, Cd, Cu, Cr(+3), Fe, Mn, Ni, Pb, and Zn. Based upon published sources, industry data, and analysis of samples, it appears that the concentrations given in the tabulation below may be routinely and reliably attained by hydroxide precipitation in the ferroalloy-ore mining and milling industry. (Reference 31).

Metal	Concentration (mg/l)	Metal	Concentration (mg/l)
As	0.05	Mn	1.0
Cd	0.05	Ni	0.05
Cu	0.03	Pb	0.10
Cr(+3)	0.05	Zn	0.15
Fe	1.0		

Some metallic pollutants of interest in the uranium-ore mining and milling industry, together with results produced by lime precipitation in conjunction with a rise in pH from 6.7 to 12.7, are shown below:

Metal	Concentration (mg/l)	
	pH=6.7	pH=12.7
Cd	1.3	less than 0.02
Fe	6.0	less than 0.1
Ni	0.13	less than 0.05
Cu	5.3	0.05
Zn	31.25	0.11
Mn	26.5	0.04

Data from previous work demonstrate the use of lime precipitation with settling in tailing pond for the base and precious metal industry. These data are summarized below. (Reference 36).

Metal	Concentration (mg/l)
Cu	0.03
Zn	0.15
Pb	0.1

Fe (total)	1.0

Other examples of the efficiency of lime precipitation as a treatment method are discussed by ore category later in this section. An important point is illustrated in the data previously presented here, however. All metals do not remain insoluble at elevated pH. Examples of that phenomenon are the variations in solubilities of lead and zinc, which are precipitated at approximately pH 9. Above pH 9, these metals rapidly resolubilize. (See Reference 37.)

Sulfide Precipitation. The use of sulfide ion as a precipitant for removal of heavy metals accomplishes more complete removal than the use of hydroxide for precipitation. Sulfide precipitation is currently being used in wastewater treatment to reduce mercury levels to extremely low levels (Reference 38). Highly effective removal of Cd, Cu, Co, Fe, Hg, Mn, Ni, Pb, Zn, and other metals from mine and mill wastes can be accomplished by treatment with either sodium sulfide or hydrogen sulfide. The use of this method depends somewhat on the availability of methods for effectively removing precipitated solids from the waste stream, and on removal of the solids to an environment where reoxidation is unlikely.

Several steps enter into the process of sulfide precipitation:

(1) Preparation of sodium sulfide. Although this product is often in oversupply from byproduct sources, it can also be made by the reduction of sodium sulfate, a waste product of acid-leach milling. The process involves an energy loss in the partial oxidation of carbon (such as that contained in coal).

$$Na_2SO_4 + 4C \longrightarrow Na_2S + 4CO \text{ (gas)}$$

(2) Precipitation of the pollutant metal (M) in the waste stream by an excess of sodium sulfide:

$$Na_2S + MSO_4 \longrightarrow MS \text{ (precipitate)} + Na_2SO_4$$

(3) Physical separation of the metal sulfide in thickeners or clarifiers, with reducing conditions maintained by excess sulfide ion.

(4) Oxidation of excess sulfide by aeration:

$Na_2S + 2O_2 \longrightarrow Na_2SO_4$

> This process usually involves iron as an intermediary and is seen to regenerate unused sodium sulfate.

On the whole, sulfide precipitation removes both heavy metals and some sulfur from waste streams but requires some energy expenditure.

In practice, sulfide precipitation can be applied only when the pH is sufficiently high (greater than about 8) to assure generation of sulfide ion rather than bisulfide or hydrogen sulfide gas. It is then possible to add just enough sulfide, in the form of sodium sulfide, to precipitate the heavy metals present as cations; alternatively, the process can be continued until dissolved oxygen in the effluent is reduced to sulfate and anaerobic conditions are obtained. Under these conditions, some reduction and precipitation of molybdates, uranates, chromates, and vanadates may occur, but ion exchange seems more appropriate for the removal of these anions.

Because of the toxicity of sulfide ion, and of hydrogen sulfide gas, the use of sulfide precipitation may require both pre-and post-treatment and close control of reagent additions. Pretreatment involves raising the pH of the waste stream to minimize evolution of H_2S, which would pose a safety hazard to personnel. If desirable, this may be accomplished at essentially the same point as the sulfide treatment, or by addition of a solution containing both sodium sulfide and a strong base (such as caustic soda). The sulfides of many heavy metals, such as copper and mercury, are sufficiently insoluble to allow essentially complete removal with extremely low residual sulfide levels. Treatment for these metals with close control on sulfide concentrations could be accomplished without the need for additional treatment. Where higher residual sulfide ion concentrations pertain, adequate aeration should be provided to yield an effluent saturated with oxygen.

Coprecipitation. In coprecipitation, materials which cannot be removed from solution effectively by direct precipitation are removed by incorporating them into particles of another precipitate, which is separated by settling, filtration, or another technique such as flotation. Current practice is exemplified by the use of barium chloride addition for radium control in the uranium industry.

Radium sulfate ($RaSO_4$), one of the least soluble substances, is soluble to 20 micrograms per liter, while allowable concentrations in drinking water are about 6 million times less. The process of coprecipitation for radium separation was perfected by M.S. Curie and has been used extensively in radiochemistry. The carrier for radium is barium, usually added as barium chloride ($BaCl_2$) in a concentration of about 10 mg/l and in the presence of more sulfate ion than is necessary to precipitate barium sulfate ($BaSO_4$). Almost all $RaSO_4$ that is present is coprecipitated, and removal to a level of about $\leq$ 1 to 3 picocurie (pC/l) or picogram per liter dissolved is current practice. The results of tests on the addition of $BaCl_2$, $BaSO_4$, and $BaCO_3$ to neutral and acidic effluents are shown in part (a) of Table VII-1. Radium removals achieved at those uranium mines and mills employing barium chloride addition alone are tabulated in part (b) of Table VII-1. Radium concentrations reflected by that table are average values based on company monitoring data and contractor sampling analyses. It is important to note that, while barium chloride dosages, influent radium concentrations, and settling or detention times are highly variable from one operation to the next, the percentage of radium removal is consistently high.

The importance of coprecipitation in the ferroalloy industry has been demonstrated by extensive experiments (References 39 and 40). In that work, molybdenum, which appears in effluents from many mines and mills as the molybdate (MoO_4^-) anion (which is not removed effectively by hydroxide or sulfide precipitation), is removed by incorporation into ferric hydroxide precipitates formed at acid pH (4.5 optimum) by the addition of ferric sulfate or ferric chloride (at levels of about 100 mg/l). Removal of resulting precipitates by filtration and flotation has been reported to yield effluents containing 0.2 mg/l for mill waters initially containing 4.9 mg/l of molybdenum (Reference 41). In a pilot-plant study using ferric sulfate and flotation recovery of precipitates, removal of more than 95 percent of influent molybdenum, to levels of 0.02 to 0.1 mg/l, has been obtained.

Since the process used for molybdenum removal is performed at acid pH, it is necessary to acidify the (typically, alkaline) mill waste stream after separation of solids in the tailing pond to effect the molybdenum removal. A base is then added to neutralize the effluent prior to discharge. For large waste stream flow, reagent costs may be an important consideration. Although molybdenum values are concentrated to about 5 percent in the precipitates removed,

TABLE VII-1. USE OF BARIUM SALTS FOR REMOVAL OF RADIUM FROM WASTEWATER

(a) REMOVAL OF RADIUM BY COPRECIPITATION

EFFLUENT pH	REAGENT	AMOUNT (mg/ℓ) OF REAGENT ADDED	RADIUM CONCENTRATIONS (picocuries/ℓ) BEFORE TREATMENT	RADIUM CONCENTRATIONS (picocuries/ℓ) AFTER TREATMENT	PERCENTAGE OF RADIUM REMOVED
Neutral	$BaSO_4$	300	100	30	70
		1000	300	70	77
	$BaCO_3$	100	470	30	94
		200	490	40	92
	$BaCl_2$*	30	800	20	97
		60	440	6	99
		100	400	2	99
		200	430	2	99
Acidic	$BaCO_3$	100	150	18	88
		200	160	20	87
		300	150	30	80
	$BaCl_2$	100	150	5 to 15	90 to 97

*Mill 9405 has reported achieving levels of < 3 pc/ℓ with the use of $BaCl_2$ alone. (See below.)

(b) REMOVAL OF RADIUM USING BARIUM CHLORIDE COPRECIPITATION ALONE

OPERATION		AMOUNT (mg/ℓ) OF $BaCl_2$ ADDED	RADIUM CONCENTRATIONS (picocuries/ℓ)				PERCENTAGE OF RADIUM REMOVED	
			BEFORE $BaCl_2$ TREATMENT		AFTER $BaCl_2$ TREATMENT			
			Total	Dissolved	Total	Dissolved	Total	Dissolved
Mills	9403^1	7.4^2	111 (±11)	–	4.09 (±0.41)	–	96.3	–
	9405^1	9.5	15.9 (±1.6)	–	< 1.0	–	> 93.7	–
	9405^{*11}	$9.5^{\dagger}$	39.2 (±3.9)	33.3 (±3.3)	5.05 (±0.5)	< 2	87.1	> 93.9
	9414^3	10	451.1 (±0.3)	437.4 (±2.1)	231.7 (±0.1)	2.7 (±0.1)	48.6	99.4
	$9415^{1,4,5}$	0.1	21.3 (±0.2)	4.9 (±0.2)	15.5 (±0.1)	0.3 (±0.1)	27.2	93.9
	9416^1	34	122.4 (±0.6)	117.5 (±2.5)	18.2 (±0.4)	12.5 (±0.6)	85.1	89.4
Mines	9402	20	40 (±0.3)^6	16.6 (±0.2)^6	16.9 (±0.3)^7	1.6 (±0.3)^7	57.7	90.4
	9402*	$20^{\dagger}$	158 (±16)	167 (±17)	7.9 (±0.8)	4.18 (±0.42)	95	97
	9411	5	35.4 (±0.3)^8	15.5 (±2.0)^8	8.4 (±0.1)^8	0.2 (±0.1)^8	76.3	98.7
	9411^{*12}	10	56.9 (±5.7)	60.2 (±6.0)	< 2	n.a.	> 96	n.a.
	$9412^{1,9}$	10.4	48.9 (±0.2)	4.7 (±0.1)	10.9 (±0.2)	1.6 (±0.1)	77.7	66.0
	9408	55	123.6 (±1.5)^{10}	37.7 (±0.3)^6	2.1 (±0.23)^{10}	0.6 (±0.1)^6	98.3	98.4
	9408*	55	142 (±14)	120 (±12)	1.12 (±0.11)	< 0.9	99	> 99

1. Data obtained from single grab sampling and analysis (April, 1976)
2. Calculated value based on average flow and annual $BaCl_2$ usage
3. Company data for January through December 1975 (Average of 12 monthly means).
4. Effluent sampled prior to final settling (April, 1976)
5. $BaCl_2$ added as a slurry with lime (4 mg/ℓ CaO)
6. Data obtained from analysis of two grab samples (April, 1976)
7. Data obtained from analysis of two 12-hour composite samples (April, 1976)
8. Company data for February 1975 (Average of 12 grab samples)
9. Final discharge to dry watercourse.
10. Colorado Dept. of Health data for period January 1973 through February 1975 (Average of 24 samples analyzed for "extractable" Ra 226)
11. Data obtained from a composite of two grab samples representing two separate influent points (May, 1977)
12. Note that the dosage has doubled apparently enhancing the treatment system efficiency.

* Updated data obtained during sampling trips occuring April May, 1977. All samples, unless otherwise indicated, are 24-hr composites.

† Dosage rates are assumed to remain the same as previous rates.

n.a. not analyzed

( ) Parenthetical values indicate analytical accuracy.

they do not appear to represent a marketable product at this time.

Vanadium is also subject to coprecipitation, with ferric hydroxide, as ferric metavanadate. The best conditions observed in laboratory studies conducted as part of this effort involve the addition, to acid or neutral solutions, of 2.5 times the stochiometric quantity of ferrous sulfate needed to form ferric metavanadate, followed by aeration and lime neutralization to a pH between 6 and 9. Reductions from up to 200 mg/l vanadium to less than 5 mg/l have been observed (Reference 42), which is in good agreement with limited field observations of soil neutralization of vanadium- and iron-bearing waste leaks. The coprecipitation process may be more economical than ion-exchange methods of removing vanadium in some instances -- particularly, with high concentrations of other solutes and low vanadium concentration. The reaction can be expressed as:

$$6\ NH_4VO_3 + 4\ FeSO_4 + 4H_2O + O_2 \longrightarrow$$

$$2\ Fe(VO_3)_3 + 2\ Fe(OH)_3 + H_2SO_4 + 3(NH_4)_2\ SO_4$$

Treatment of the metavanadate with ferrous ion and subsequent aeration drives the above reaction to the right. It is not until the pH is elevated, however, that coprecipitation of the ferric metavanadate and ferric hydroxide is observed.

Other Precipitation Systems. Other types of precipitation systems have been employed, such as those used for the precipitation of sulfate (Reference 43), fluoride (as calcium fluoride), or others (Reference 44). Starch-xanthate complexes have recently been reported to be effective in aiding precipitation of a variety of metals, including Cd, Cr, Cu, Pb, Hg, Ni, Ag, and Zn (Reference 45). Scavenging or coprecipitation studies have been conducted on municpal wastewater (Reference 46). In specialized cases, precipitation may be induced by oxidation, which produces a less soluble heavy-metal product. The chlorine oxidation of Co(+2) to Co (+3) at a pH of approximately 5 produces the insoluble Co_2O_3 (xH_2O). Oxidation of Fe(+2) to Fe(+3) results in the precipitation of hydrous ferric oxide, even at relatively low pH. Oxidation of As(+3) to As(+4) improves precipitation removal (Reference 45). The use of oxidation is further discussed later in this section.

Reduction

Reduction techniques have particular applicability to the removal of hexavalent chromium and copper from waste streams in the ferroalloy-ore mining and milling industry. Copper is often recovered in current practice by reduction of the metal and subsequent deposition on scrap iron in the waste stream (cementation). Since the effluent levels resulting from cementation are still high, generally 10 mg/l or more, it is necessary to follow use of this process with another removal step, such as hydroxide precipitation.

Reduction of chromates to trivalent chromium, with subsequent precipitation of the chromium as the hydroxide, is a standard waste-treatment practice in a number of industries and may find application in the ore mining and dressing industry, where leaching practices give rise to wastewater contaminated with chromates. Commonly used reducing agents include sulfur dioxide and ferrous salts of iron. With sulfur dioxide and a pH of 2.5, chromate may be reduced rapidly and completely. Removal of the $Cr(OH)_3$ precipitate formed in treatment of the relatively dilute wastes to be expected in mill effluents may prove difficult, necessitating careful management of the treatment system and the use of flocculants such as $Fe(OH)_3$ to aid in settling. Effluent levels of 0.5 mg/l of total chromium and 0.05 mg/l of hexavalent chromium may be reliably attained by the treatment (Reference 47).

Sodium borohydride reduction has been applied to reducing soluble mercury levels in chlor-alkali and mercury processing plants and to reducing lead levels in wastes arising in the tetra-alkyllead manufacturing process (U.S. Patents 3,736,253, 3,764,528, and 3,770,423). Stannous (tin) compounds have been used for the reductive deposition of palladium during electroplating processes. Electroreduction of metals is widely practiced in electrowinning and electrorefining systems for copper, nickel, cobalt, and other metals.

Treatment in the ore mining and dressing industry differs from the above techniques, chiefly because of the lower concentrations of soluble, reducible species and because of the presence of numerous other reducible species in the wastewater. Unless preconditioning of treated waters is employed, excessive reducing agent consumption may occur. Secondary recovery systems (settling, filters, etc.) may be necessary to permit removal of reduced components. The recovery of values from waste residues is a potential option with this treatment method. In some instances, application of this process option to internal streams prior to discharge and/or combination with other waste streams may offer substantial enhancement of value recovery from treatment products.

Oxidation, Aeration, and Air Stripping

A number of the waste components resulting from mining and milling may be removed or rendered less harmful by oxidation or removal to the atmosphere. Among these are cyanide, sulfide, ammonia, and a variety of materials presenting high COD levels. The simplest approach to effecting these processes is aeration of the waste stream, which occurs naturally in pumping it and in distributing it at the tailing pond. More elaborate implementation achieves more complete and rapid results in air strippers, and by controlled introduction of stronger oxidants, such as chlorine or ozone.

Cyanide ($CN-$) is removed by oxidation to cyanate ($CNO-$) and, ultimately, to CO_2 and N_2. This is accomplished in standard practice by rapid chlorination at alkaline pH (about 10.5) using caustic soda. The probable reaction with excess chlorine has been expressed as:

$$2NaCN + 5Cl_2 + 12NaOH \longrightarrow N_2 + 2Na_2CO_3 + 10NaCl + 6H_2O$$

A pH of 10 to 11 is recommended for operating conditions. This process may be performed on either a batch or continuous process. Approximately 2.72 kg (6 lb) each of caustic soda and chlorine are normally required to oxidize 0.45 kg (1 lb) of cyanide. If metal-cyanide complexes are present, extended chlorination for several hours may be necessary.

In treatment of mill effluent in the gold milling industry, some cyanide is lost in the process and is present in the mill tailings. Some of the cyanide decomposes in the tailing pond, and it appears that a high level of removal is generally effected by naturally occurring oxidation in tailing ponds. Except where cyanide is used as a leaching reagent, high concentrations of cyanide are not normally encountered. The use of cyanide as a depressant in the flotation process is an additional source of cyanide in wastewater. Effluent levels characteristically encountered are less than 0.05 mg/l total cyanide.

Where removal of low levels of cyanide is required, aeration devices, auxiliary ponds or longer retention times may frequently be adequate to achieve acceptable effluent quality. Complete destruction of cyanide in mill treatment systems may be achieved by the use of chlorination, ozonation, or electrolytic decomposition.

Alternatively, hydrogen peroxide may be employed to remove cyanide from mill effluents by oxidation according to the equation

$$H_2O_2 + CN^- \text{-----}> H_2O + CNO^-$$

This process which is implemented in a DuPont patent among others, quantitatively converts cyanide to the much less toxic cyanate, but does not provide complete reaction to carbon dioxide and nitrogen.

Aeration in ponds can be interrupted by winter ice cover and cyanide concentrations above acceptable levels may occur. One molybdenum operation is experimenting with a cyanide removal process that uses hydrogen peroxide to supplement aeration in winter. Thirty percent H_2O_2 is gravity-fed from barrels via stainless steel needle values, to the tailings decant in a baffled flume that provides intimate mixing. Tailings decant is retained for several hours before discharge. Total cyanide concentrations have been reduced by 30 to 40 percent with dosage ratios of H_2O_2 to CN of up to 100 on a weight basis. The process is expected to be more effective in treating free cyanide ion and unstable cyanide complexes than the stable heavy metal cyanide complexes that are typically present in decant water from these operations. Ubiquitous iron-cyanide complexes, for example, are not oxidized significantly by hydrogen peroxide. This may explain why H_2O_2 treatment appears to have limited effectiveness as gauged by total cyanide analysis.

Effective and proper use of chlorination or ozonation should result in complete destruction of cyanide in mill treatment systems. At locations where very low levels are encountered in wastewater streams, aeration devices, auxiliary ponds, or long retention times may provide removal to below acceptable levels.

Ammonia used in a solvent extraction and precipitation operation at one milling site is removed from the mill waste stream by air stripping. The countercurrent-flow air stripper used at this plant operates with a pH of 11 to 11.7 and an air/liquid flow ratio of 0.83 cubic meter of air per liter water (110 cubic feet of air per gallon of water). Seventy-five percent removal of ammonia is achieved, reducing total nitrogen levels for the mill effluent to less 5 mg/l, 2 mg/l of which is in the form of nitrates. Ammonia may also be removed from waste streams through oxidation to nitrate by aeration--or, more rapidly, by ozonation--or use of chemical oxidants, although these procedures are less desirable due to the impact of nitrates on the receiving water.

The removal of a variety of COD-producing pollutants from effluent streams by oxidation in the tailing ponds and/or delivery lines is evident in data from visited sites. Where high reagent dosages or other process factors lead to elevated effluent COD levels, aeration or the use of stronger oxidants may be of value. In general, the use of strong oxidants in the tailing pond will be highly undesirable, since the oxidation of sulfide minerals in the tails can lead to increased acid production and greater solubility of ore constituents, including heavy metals. Aeration will be best practiced in other impoundments also.

Adsorption

Activated carbon is a sorptive material characterized by high surface area within its internal pore system. Pores generally range from 10 to 100 Angstrom units (0.001 to 0.01 micrometer), and surface areas of up to 1000 square meters/gram are considered normal for carbons of this type. Due to the dimensions of the pores, to the highly convoluted internal surface (and, thus, very high surface area), and to the residual organic contents of carboxyic, carbonyl, and hydroxyl compounds, activated carbon exhibits adsorptive, absorptive, and slight residual ion-exchange capabilities. In contrast to alumina, silica gel, and other adsorbents, however, activated carbon exhibits a relatively low affinity for water. Compounds which are readily removed by activated carbon include aromatics, phenolics, chlorinated hydrocarbons, surfactants, organic dyes, organic acids, higher-molecular-weight alcohols, and amines. Current applications of this material also center around the control and removal of color, taste, and odor components in water.

Activated carbon has been shown to significantly reduce concentrations of a variety of inorganic salts, including most heavy metals. Lead concentrations have been reduced from 100 mg/l to 0.5 mg/l (Reference 48). Reports of Hg, V, Cr, Pb, Ni, Cd, Zn, Fe, Mn, Ca, Al, Bi, Ge, As, Ba, Se, and Cu removal have appeared in the literature--most often, as results of laboratory scale treatment (References 49 and 45).

In addition to use in tertiary sewage treatment, activated carbon has found a variety of industrial-waste applications. At one facility, phenols are removed from 600 cubic meters (150,000 gallons) per day of chemical plant wastewater containing 62,000 mg/l of total dissolved solids (Reference 50). Influent and effluent levels for this treatment facility are 100 mg/l and less than 1 mg/l of phenol, respectively. As in this operation, carbon may be regenerated in a furnace with approximately 95-percent carbon recovery to reduce materials cost for the operation.

In addition to the economics of operation dictating regenerative processes, recovery of metal values using the principles of this treatment is possible. Some indication of the economic success of this approach may be gained from the reported viability of the "resin-in-pulp" or "carbon-in-pulp" process employed at mill 4105 in the gold-recovery circuit. In this case, cyano-complexes of gold (and, probably, other metals) are reversibly adsorbed from alkaline solution by activated carbon. Activated-carbon treatment of acid mine water has been used for iron (+2) removal (Reference 51).

The application of carbon adsorption, or adsorption by other materials (such as peat), to mining and milling wastewater is more likely to be limited by cost than by technical feasibility. Removal of flotation or solvent-extraction reagents from waste streams may be practical in some operations, if waste streams are segregated. Carbon adsorption could be an important factor in achieving a high degree of water recycle in flotation mills where reagents or decomposition products in the feed water would interfere with processing.

Other Adsorption Methods. While activated carbon is one specific adsorbent used for wastewater treatment, there are many additional materials which show varying adsorptive capacities for wastewater constituents. Many of these candidate sorbing media have been evaluated only in a preliminary fashion under full scale conditions, and few of these have been evaluated with reference to behavior in actual mine/mill effluents.

Reported adsorbing species include tailing materials (Reference 52), waste wool (Reference 53), silica gel, alumina, hydrous zirconium oxide (Reference 54), peat moss (Reference 55), hydrous manganese oxides (Reference 56), and others. The sorptive capacity of various soils is currently under study in conjunction with increased utilization of spray irrigation as a method of wastewater disposal (Reference 57).

To date, little experience in large-scale wastewater disposal involving waters similar to mine/mill effluents has been reported for land disposal by spray irrigation. Capital costs, operating costs, and performance experience with municipal, food-industry, and paper-industry waste disposal, however, suggest the potential desirability of this procedure (Reference 58). Any spray-irrigation disposal of mine/mill wastes must be preceded by settling systems or other treatments to reduce the suspended-solid load.

Ion Exchange

Ion exchange is basically a process for removal of various ionic species in or on fixed surfaces. During the fixing process, ions in the matrix are exchanged for soluble ionic species. Cationic, anionic, and chelating ion exchangers are available and may be either solid or liquid. Solid ion exchangers are generally available in granular, membrane, and bead forms (ion-exchange resins) and may be employed in upflow or downflow beds or columns, in agitated baskets, or in cocurrent- or countercurrent-flow modes. Liquid ion exchangers are usually employed in equipment similar to that employed in solvent-extraction operations (pulsed columns), mixed settlers, rotating-disc columns, etc.). In practice, solid resins are probably more likely candidates for end-of-pipe wastewater treatment, while either liquid or solid ion exchangers may be utilized in internal process streams.

Individual ion-exchange systems dc not generally exhibit equal affinity or capacity for all ionic species (cationic or anionic) and, so, may not be suited for broad-spectrum removal schemes in wastewater treatment. Their behavior and performance are usually dependent upon pH, temperature, and concentration, and the highest removal efficiencies are generally observed for polyvalent ions. In wastewater treatment, some pretreatment or preconditioning of wastes to adjust suspended solid concentrations and other parameters is likely to be necessary.

Progress in the development of specific ion-exchange resins and techniques for their application has made the process attractive for a wide variety of industrial applications in addition to water softening and deionization. It has been used extensively in hydrometallurgy--particularly, in the uranium industry--and in wastewater treatment (where it often has the advantage of allowing recovery of marketable products). This is facilitated by the requirement for periodic stripping or regeneration of ionic exchangers. If regeneration produces a solution waste, its subsequent treatment must be considered.

Table VII-2 shows different types of ion-exchange resins and the range of conditions and variety of purposes for which they are employed.

Disadvantages of using ion exchange in treatment of mining and milling wastewater are relatively high costs, somewhat limited resin capacity, and insufficient specificity--especially, in cationic exchange resins for some applications.

Although it is suitable for complete deionization of water, ion exchange is generally limited in this application, by economics and resin capacity, to the treatment of water containing 500 mg/l or less of total dissolved solids. Since TDS levels in mining and milling effluents are often higher than this level, application of ion exchange to the economic reduction of total dissolved solids at high flow rates must be evaluated.

For recovery of specific ions or groups of ions (e.g., divalent heavy-metal cations, or metal anions such as molybdate, vanadate, and chromate), ion exchange is applicable to a much broader range of solutions. This use is typified by the recovery of uranium from ore leaching solutions using strongly basic anion-exchange resin. As additional examples, one may consider the commercial reclamation of chromate plating and anodizing solutions, and the recovery of copper and zinc from rayon-production wastewaters (Reference 59). Chromate plating and anodizing wastes have been purified and reclaimed by ion exchange on a commercial scale for some time, yielding economic as well as environmental benefits. In tests, chromate solutions containing levels in excess of 10 mg/l chromate, treated by ion exchange at practical resin loading values over a large number of loading elution cycles, consistently produced an effluent containing no more than 0.03 mg/l of chromate.

High concentrations of ions other than those to be recovered may interfere with practical removal. Calcium ions, for example, are generally collected along with the divalent heavy-metal cations of copper, zinc, lead, etc. High calcium ion concentrations, therefore, may make ion-exchange removal of divalent heavy-metal ions impractical by causing

TABLE VII-2. PROPERTIES OF ION EXCHANGERS FOR METALLURGICAL APPLICATIONS

DESIRED CHARACTERISTIC		GENERALLY RECOMMENDED APPLICATION								
		CATION EXCHANGERS					ANION EXCHANGERS			
		Inorganic		Organic			Weakly Basic		Strongly Basic	
				Sulfonated		Carboxylic Resin	Granular	Bead	Granular	Bead
				Coal	Resins					
		Zeo-Dur	Decalso	Zeo-Karb	Permutit Q	Permutit H-70	De-Acidite	Permutit W	Permutit A	Permutit S
CHEMICAL STABILITY TO:	Acids			●	●	●	●	●	●	●
	Alkalies				●	●	●	●	●	●
	Oxidation				●	●		●		●
	Temperature				●	●		●		●
	Organic Solvents	●	●		●			●		●
PHYSICAL STABILITY FOR:	Removal of weak acids								●	●
	Removal of strong acids						●	●	●	
	High regeneration efficiency			●		●	●			
	High capacity		●		●	●	●		●	●
	High porosity		●	●			●			
	Hydrogen exchange at low pH			●	●					
	Salt splitting								●	●
	pH range (operating)	6.2 to 8.7	6.9 to 7.9	0 to 11	0 to 13	3.5 to 12	0 to 12	0 to 13.9	0 to 13.9	0 to 13.9

SOURCE; Reference 54

rapid loading of resins and necessitating unmanageably large resin inventories and/or very frequent elution steps. Less difficulty of this type is experienced with anion exchange. Available resins have fairly high selectivity against the common anions, such as Cl(-) and SO_4(-2). Anions adsorbed along with uranium include vanadate, molybdate, ferric sulfate anionic complexes, chlorate, cobalticyanide, and polythionate anions. Some solutions containing molybdate prove difficult to elute and have caused problems.

Ion-exchange resin beds may be fouled by particulates, precipitation within the beds, oils and greases, and biological growth. Pretreatment of water, as discussed earlier, is therefore, commonly required for successful operation. Generally, feed water is required to be treated by coagulation and filtration for removal of iron and manganese, CO_2, H_2S, bacteria and algae, and hardness. Since there is some latitude in selection of the ions that are exchanged for the contaminants that are removed, post-treatment may or may not be required.

Since, in many cases, calcium is present in ore mining and milling wastewater in appreciably greater concentrations than are the heavy-metal cations whose removal to low levels is sought, use of ion exchange in that mode would be expensive and little advantage would be offered over lime or sulfide precipitation. For the removal of anions, however, the relatively high costs of ion-exchange equipment and resins may be offset partially or totally by the recovery of a marketable product. This has been demonstrated in the removal of uranium from mine water. The removal of molybdate ion from ferroalloy-ore-milling wastewater has been investigated, with promising results, in a pilot-plant study. Treating raw wastewater containing up to 24 mg/l of molybdenum, the pulsed-bed ion-exchange pilot plant produced effluents consistently containing less than 2 mg/l. Continuous operation was achieved for extended periods of time, with results indicating possible breakeven or profitable operation through sale of the recovered molybdenum. The application of this technique at any specific site will depend upon a complex set of factors, including resin loading achieved, pretreatment required, and the complexity of processing needed to produce a marketable product from eluent streams.

The practicality of the ion-exchange process will be enhanced by practices such as waste segregation, recycle, etc., which allow the treatment of smaller volumes of more concentrated solutions. Similar factors apply to the treatment of mining and milling waste streams bearing vanadate and chromate anions, although prior experience in ion-exchange recovery of these materials should aid the development of treatment schemes for such wastes.

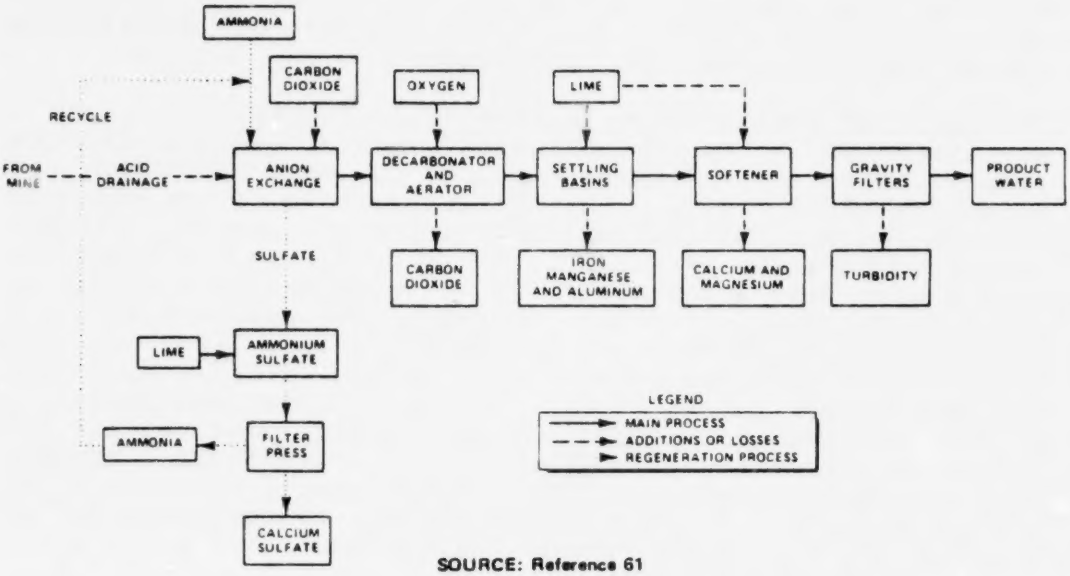
Modified Desal Process. A demonstration plant for generating potable water from acid coal-mine drainage, in operation since early 1973, treats 3,028 cubic meters (800,000 gallons) per day of water which contains pollutant loadings similar to those of acid mine drainage (Reference 60). The plant was originally designed for a capacity of 1,893 cubic meters (500,000 gallons) per day, but it is expected that the plant's capacity can be further increased to 3,785 cubic meters (1,000,000 gallons) per day through use of improved operating techniques.

The Modified Desal Process portrayed in Figure VII-5 is a variation of a system originally developed to produce potable water from brackish supplies by means of cation and anion exchange resins. The primary purpose of ion exchange in treating acid mine water, however, is to remove sulfate, so only an anion-exchange resin is necessary. The process uses a weak base anion resin in the bicarbonate form to replace sulfate or other anions. The solution of metal bicarbonates is aerated to oxidize ferrous iron to the ferric form and to purge the carbon dioxide gas. The increase in pH causes iron, aluminum, and manganese to precipitate as insoluble hydrous oxides. Some calcium and magnesium carbonates also precipitate. To produce improved quality water, well within potable limits lime treatment precipitates more calcium and magnesium by converting the bicarbonates into less soluble carbonates.

The exhausted resin is regenerated with ammonium hydroxide, which converts the resin to the free-base form. Introduction of carbon dioxide converts the resin back to the bicarbonate form, and the regenerated solution of ammonium sulfate is processed to recover the ammonia through lime addition. The resultant calcium sulfate is transported to mine pits for disposal. Regeneration occurs after about 18 hours of operation, and the plant currently utilizes the original ion-exchange resin.

Operating data for the plant are shown in Table VII-3. It is felt that this system, or a modification thereof, might provide effective removal of sulfate and dissolved solids in the ore mining and dressing industry.

Figure VII-5. DIAGRAM OF MODIFIED DESAL PROCESS


AMMONIA
CARBON DIOXIDE
OXYGEN
LIME
RECYCLE
FROM MINE
ACID DRAINAGE
ANION EXCHANGE
DECARBONATOR AND AERATOR
SETTLING BASINS
SOFTENER
GRAVITY FILTERS
PRODUCT WATER
SULFATE
CARBON DIOXIDE
IRON MANGANESE AND ALUMINUM
CALCIUM AND MAGNESIUM
TURBIDITY
LIME
AMMONIUM SULFATE
AMMONIA
FILTER PRESS
CALCIUM SULFATE
LEGEND
MAIN PROCESS
ADDITIONS OR LOSSES
REGENERATION PROCESS

SOURCE: Reference 61

TABLE VII-3. ANALYTICAL DATA FOR MODIFIED DESAL PROCESS

PARAMETER	CONCENTRATION (mg/ℓ)	
	RAW WASTEWATER	EFFLUENT WATER
pH	3.7*	9.5*
Total hardness ($CaCO_3$)	395	184
TDS	1,084	284
Calcium ($CaCO_3$)	295	85
Magnesium ($CaCO_3$)	100	99
Iron	101	0.2
Sulfate	648	192

*Value in pH units

Present operating costs for water produced at the Phillipsburg, Pennsylvania, plant are $0.40 to 0.50 per 3.8 cubic meters (1,000 gallons) of water. However, a considerable reduction in cost might be achieved for the mining industry for two reasons. The first is that the demonstration plant contains much instrumentation and many features that would be unnecessary in a facility designed merely for production. Secondly, integration of the ion-exchange system with presently existing lime-neutralization plants could eliminate the necessity for many features of the Modified Desal Process system.

Although the cost for treating 3.8 cubic meters (1,000 gallons) of raw mine drainage appears favorable, volumes in excess of 57,000 cubic meters (15,000,000 gallons) of drainage generated daily at many facilities require a substantial total investment in time, material resources, and energy. Also, individual treatment plants with design capacities of up to 34,065 cubic meters (9,000,000 gallons) per day would necessitate the installation of multiple ion-exchange units at most discharge outfalls. This configuration would greatly decrease cost effectiveness for a treatment aimed specifically at removing sulfate and dissolved solids.

Ultrafiltration and Reverse Osmosis

Ultrafiltration and reverse osmosis are similar processes in which pressure is used to force water through membranes which do not allow passage of contaminants. They differ in the scale of contaminants passed and in the pressures required. Ultrafiltration generally retains particulates and materials with a molecular weight greater than 500, while reverse-osmosis membranes generally pass only materials with a molecular weight below 100. (Sodium chloride, although below a molecular weight of 100, is retained, allowing application to desalinization.) Pressures used in ultrafiltration generally range from 259 to 517 cm of Hg (50 to 100 psi), while reverse osmosis is run at pressures ranging from 2,068 to 9,306 cm of Hg (400 to 1,800 psi).

Ultrafiltration has been applied on a significant commercial scale to the removal of oil from oil emulsion, yielding a highly purified water effluent and an oil residue sufficiently concentrated to allow reuse, reclamation, or combustion. Equipment is readily available, and present-day membranes are tolerant of a broad pH range. Application of ultrafiltration to mining and milling waste streams, where high dosages of oils are used in flotation--as at a formerly operated manganese mill--may provide a practical technique for removing these waste components, possibly allowing reuse as well.

Reverse osmosis (RO) is conceptually similar to ultrafiltration. It also involves the application of an external pressure to a solution in contact with a semipermeable membrane to force water through the membrane while excluding both soluble and insoluble solution constituents. In its rejection of soluble constituents, reverse osmosis performs a water-treatment function not fulfilled by ultrafiltration systems under simple operating conditions.

Reverse osmosis is considerably less tolerant of input-stream variations in conditions and requires, in general, considerable pretreatment. Concentration of wastes is generally limited by saturation of solutions and the formation of precipitates, which can decrease the effectiveness of the apparatus. As a result, residual volumes of waste in the mining and milling industry would, in many cases, be unmanageably large. A pilot-plant operation has been run on mine drainage streams, and production of a high-quality water effluent has been shown to be technically feasible. Pretreatment requirements, costs, and the problems of disposal of residual wastes make the practicality and economic achievability important considerations.

Reverse osmosis has been demonstrated capable of rejecting heavy-metal species from purified water streams with a high degree of efficiency (Table VII-4). Reverse-osmosis systems have been evaluated for acid mine water treatment (References 62 and 63). Related studies have been conducted with metal finishing effluents (Reference 64). In most instances, pretreatment of water, and conditioning with respect to pH, temperature, and suspended-solid levels, is necessary for reverse-osmosis module use. Membrane lifetime and constancy of efficiency are both adversely affected by inadequate treatment of waters prior to membrane contact. In general, laboratory performance of reverse-osmosis systems has shown somewhat higher purification efficiencies than have been observed in pilot-plant operations (Reference 45). The present state-of-the-art with regard to RO technology indicates that details of extrapolation of laboratory and current pilot-plant data to full-scale operation need to be worked out. Data on membrane lifetime, operating efficiency, rejection specificity, and other factors remain to be more fully quantified.

TABLE VII-4. REJECTION OF METAL SALTS BY REVERSE-OSMOSIS MEMBRANES

PARAMETER	TYPICAL REJECTION PERCENT
Iron	99
Magnesium	98
Copper	99
Nickel	99.2
Chromium (hexavalent)	97.8
Strontium	99
Cadmium	98
Silver	96
Aluminum	99

SOURCE: Reference 47

High-Density-Sludge Acid Neutralization

The conventional lime neutralization of acid or mine wastes usually leads to the formation of low-density sludges which are difficult to dewater (flocs). The use of ground limestone avoids this problem but does not allow for the attainment of pH levels necessary to effectively remove such metals as zinc and cadmium. A process which utilizes extensive recycle of the previously precipitated sludge allows the attainment of sludges of much higher density, thus allowing more rapid sedimentation of the sludges ultimately produced and easing solid-disposal problems.

Solvent Extraction

Solvent extraction is a widely utilized technique for the separation and/or concentration of metallic and nonmetallic species in the mineral processing industry. It has been applied to commercial processing of uranium, vanadium, tungsten, thorium, rhenium, rare earths, beryllium, columbium, copper, zirconium, molybdenum, nickel, boron, phosphoric acid, and others (References 65 and 66). Reagent-processing equipment for this technique is highly developed and generally available (Reference 67). It is anticipated that such equipment would require modification to be applicable to treating the low levels of soluble metals in most waste streams. Pretreatment and post-treatment of waters treated by this technique would probably be required to control influent pH, suspended solids, and other parameters, as well as effluent organic levels. It is likely that this treatment strategy may be most applicable in internal process streams or as an add-on for the recovery of values from waste-concentration streams such as distillate or freeze residues, reverse-osmosis brines, etc.

Because of the speculative nature of solvent extraction as applied to wastewater treatment, the unknown costs of reagents, and possible pretreatment/post-treatment demands, accurate treatment or capital costs for this option do not appear readily derivable at this time.

Evaporation and Distillation

Evaporation may be employed as a wastewater-treatment technique in a variety of ways:

(1) Total evaporation of wastewater may produce solid residues and eliminate effluent water discharge.

(2) Concentration of wastewater by evaporation may balance dilution by makeup and infiltration water and allow for an approach to total recycle, thus minimizing discharge volume. The buildup of detrimental species upon evaporation will normally require a bleed stream from the evaporation system, thus precluding total water recycle. A bleed stream, of course, might be handled by total evaporation, rather than by discharge to a waterway.

(3) Concentration by evaporation may allow subsequent removal of concentrated wastewater components to acceptable levels for smaller-volume discharge or reuse.

(4) Ultimately, complete distillation of wastewater may allow the almost total reuse or recycle of contained water, while rendering discharge unnecessary and allowing potential recovery of values from nonvolatile residues. In the absence of recoverable values, disposal of sludge resulting from distillation might become a problem of substantial magnitude. The presence of volatile wastes in the effluent may require additional treatment of distillate to achieve adequate quality for some uses.

Energy sources for evaporation may be artificial (steam, hot gases, and electricity) or natural (solar, geothermal, etc.). In present practice, many of the mining and milling operations in the Western and Southwestern United States employ solar evaporation as a principal means of water treatment. Evaporative losses of water at some installations may exceed 7,572 cubic meters (2,000,000 gallons) per year for each 0.4 hectare (1 acre) of evaporative surface; with adequate surface acreage, this loss may allow for zero-effluent-discharge operation. At present, this evaporated water is not collected for reuse at these operations.

A multistage flash-distillation process has been applied to treat acid mine drainage (from a coal mine) in a pilot plant (Reference 68). The process is mechanically complex but results in a solid residue and essentially pure water, suitable for human consumption. This approach to pollution control involves the use of considerable energy associated with vaporizing vast volumes of water. Its technical applicability to treating mine water has been demonstrated, but it is not clear that organic wastes potentially present in mill effluents would be successfully controlled by such a process.

Techniques for Reduction of Wastewater Volume

Pollutant discharges from mining and milling sites may be reduced by limiting the total volume of discharge, as well as by reducing pollutant concentrations in the waste stream. Volumes of mine discharges are not, in general, amenable to control, except insofar as the mine water may be used as input to the milling process in place of water from other sources. Techniques for reducing discharges of mill wastewater include limiting water use, excluding incidental water from the waste stream, recycle of process water, and impoundment with water lost to evaporation or trapped in the interstitial voids in the tailings.

In most of the industry, water use should be reduced to the extent practical, because of the existing incentives for doing so (i.e., the high costs of pumping the high volumes of water required, limited water availability, and the cost of watertreatment facilities). Incidental water enters the waste stream primarily through precipitation directly and through the resulting runoff influents to tailing and settling ponds. By their very nature, the water-treatment facilities are subject to precipitation inputs which, due to large areas, may amount to substantial volumes of water. Runoff influxes are often many times larger, however, and may be controlled to a great extent by diversion ditches and (where appropriate) conduits. Runoff diversion exists at many sites and is under development at others.

Recycle of process water is currently practiced primarily where it is necessary due to water shortage, or where it is economically advantageous because of high water costs. Recycle to some degree is accomplished at many ore mills, either by reclamation of water at the mill or by the return of decant water to the mill from the tailing pond or secondary impoundments. Recycle is becoming, and will continue to become, a more frequent practice. The benefits of recycle in pollution abatement are manifold and frequently are economic as well as environmental. By reducing the volume of discharge, recycle not only reduces the gross pollutant load, but also allows the employment of abatement practices which would be uneconomic on the full waste stream. Further, by allowing concentrations to increase, the chances for recovery of waste components to offset treatment cost--or, even, achieve profitability--are substantially improved. In addition, costs of pretreatment of process water--and, in some instances, reagent use--may be reduced.

Recycle of mill water almost always requires some treatment of water prior to its reuse. In many instances, however, this may entail only the removal of solids in a thickener or tailing basin. This is the case for physical processing mills, where chemical water quality is of minor importance, and the practice of recycle is always technically feasible for such operations. In flotation mills, chemical interactions play an important part in recovery, and recycled water can, in some instances, pose problems. The cause of these problems, manifested as decreased recoveries or decreased product purity, varies and is not, in general, well-known, being attributed at various sites and times to circulating-reagent buildup, inorganic salts in recycled water, or reagent decomposition products. Experience in arid locations, however, has shown that such problems are rarely insurmountable. In general, plants practicing bulk flotation on sulfide ores can achieve a high degree of recycle of process waters with minimal difficulty or process modification. Complex selective flotation schemes can pose more difficulty, and a fair amount of work may be necessary to achieve high recovery with extensive recycle in such a circuit. Numerous examples where this has been achieved may be cited (Reference 69). Problems of achieving successful recycle operation in such a mill may be substantially alleviated by the recycle of specific process streams within the mill, thus minimizing reagent crossover and degradation. The flotation of non-sulfide ores (such as scheelite) and various oxide ores using fatty acids, etc., has been found to be quite sensitive to input water quality. Attempts at water recycle in such operations have posed severe problems, and successful operation may require a high degree of treatment of recycle water. In many cases, economic advantage may still exist over treatment to levels which are acceptable for discharge, and examples exist in current practice where little or no treatment of recycle water has been required.

Technical limitations on recycle in ore leaching operations center on inorganic salts. The deliberate solubilization of ore components, most of which are not to be recovered, under recycle operations can lead to rapid buildup of salt loads incompatible with subsequent recovery steps (such as solvent extraction or ion exchange). In addition, problems of corrosion or sealing and fouling may become unmanageable at some points in the process. The use of scrubbers for air-pollution control on roasting ovens provides another substantial source of water where recycle is limited. At leaching mills, roasting will be practiced to increase solubility of the product material. Dusts and fumes from the roasting ovens may be expected to contain appreciable quantities of soluble salts. The buildup of salts in recycled scrubber water may lead to plugging of spray nozzles, corrosion of equipment, and decreased removal effectiveness as salts crystallizing out of evaporating scrubber water add to particulate emissions.

Impoundment is a technique practiced at many mining and milling operations in arid regions to reduce point discharges to, or nearly to, zero. Its successful employment depends on favorable climatic conditions (generally, less precipitation than evaporation, although a slight excess may be balanced by process losses and retention in tailings and product) and on availability of land consistent with process-water requirements and seasonal or storm precipitation influxes. In some instances where impoundment is not practical on the full process stream, impoundment and treatment of smaller, highly contaminated streams from specific processes may afford significant advantages.

Electrodialysis

Electrodialysis is fundamentally similar to both reverse osmosis and ultrafiltration to the extent that it employs semipermeable membranes to allow separation of soluble cationic and anionic impurities from water. An imposed electrical field is used to provide a driving force for ion migration, in analogy to either osmotic or external pressure in reverse-osmosis, dialytic, or ultrafiltration systems.

Electrodialysis is generally employed in the treatment of waters containing less than 5,000 to 10,000 mg/l of dissolved solids to achieve final levels of less than 500 mg/l (Reference 44). Applications have been reported in desalinization of seawater involving feed water containing 38,000 mg/l chloride and producing a product water containing 500 mg/l chloride (Reference 54).

To date, electrodialysis has not been employed in large-scale operations within the mining/milling industry segments reviewed and studied in this program. The potential for isolation and recovery of byproduct or waste values exists but has not been confirmed.

Freezing

This process depends on the formation of pure ice crystals from the contaminated solution being treated. Results of freezing experiments on acid mine-drainage samples (from a coal mine) indicate that suspended solids act as condensation nuclei and, if present, are entrained with the "pure" ice obtained. Once solids have been removed, of course, the mine drainage may still contain other contaminants.

Experimentally, agitation and slow freezing rates have allowed reductions in dissolved materials in the range of 35 to 90 percent (Reference 45).

This process results in a concentrated stream, which still requires treatment. It has a theoretical advantage over distillation because only about one-sixth of the energy should be required. Laboratory-scale experiments indicate it may be a feasible treatment technique for mine and mill water treatment, but it has not been fully tested.

Biological Treatment

The ability of various biota--both flora and fauna--to assimilate soluble constituents from contacting waters is being documented with increasing frequency. In general, these studies have considered the undesirability of such assimilations, rather than viewing them from the standpoint of potential water-treatment options or systems. If trace or toxic constituents can be metabolized, detoxified, or fixed by various organisms, the periodic removal of organisms containing concentrates of these materials may be a viable removal mechanism.

The use of this technique at one facility visited involves a combination of sedimentation ponds and biological treatment in the form of meanders. The meander system is an artificial system designed to contain--and, thereby, control--excessive algal growth and the associated heavy metals which are trapped and assimilated by the algae (Reference 70). The algal growth occurs naturally and was a problem associated with the discharge prior to installation of the present system. The system was designed as a series of broad, shallow, rapidly flowing meanders, which increase the length of the treatment section and encourage the growth of algae before discharge, while simultaneously trapping any suspended heavy metals. To prevent the algae and the associated heavy metals from escaping the system, an additional final sedimentation pond is placed at the end of the system.

The system can be effective if sufficient land is available to allow the construction of an adequate meander system, and if the climate is such that algae growth is not precluded during parts of the year. These conditions effectively prevent widespread application of this treatment technique.

EXEMPLARY TREATMENT OPERATIONS BY ORE CATEGORY

The manner in which ore mine and mill operators have approached the design and construction of treatment and control facilities varies from quite simple to somewhat sophisticated (utilizing recycling, zero-discharge operations). To attain extensive recycling or zero discharge, extensive process changes and/or redesign have often been necessary. Performance of the many vaired operations used in each ore category varies with the operating characteristics of the facility, the ore mineralogy, and other factors. Descriptions, by ore category, of the treatment and control processes used in the ore mining and dressing industry and the consequent treatment levels attained are included here to provide a more complete explanation and examination of the control and treatment technology currently in use.

Iron Ore

This discussion includes examples of mines that have discharges (Subcategory I), mills which employ physical and chemical beneficiation and mills which employ only physical benefication (Subcategory II), and mills using magnetic- and physical-separation methods (Subcategory III).

Mining Operations. Mine 1105 is an open-pit operation that accumulates water. Water is pumped directly from the pit to a settling pond of sufficient volume to remove suspended solids prior to discharge. No chemical coagulants are used, because the suspended-solid concentration generally is less than 10 mg/l. Because this operation produces low levels of dissolved components, dissolved-solid treatment is unnecessary. Suspended-solid concentrations after treatment have been observed to remain low, but historical data obtained during periods of high rainfall and high pumping rates are lacking.

Table VII-5 is a compilation of data measured in this study and by the operators. It can be observed that many of the parameters measured appear to increase in the effluent stream after treatment. Measurements made during this study were confirmed by duplicate industry sample analysis.

TABLE VII-5. CHEMICAL CHARACTERISTICS OF SETTLING-POND DISCHARGE AT MINE 1105

PARAMETER	AVERAGE MINE-DISCHARGE CONCENTRATION (mg/ℓ)		AVERAGE SETTLING-POND DISCHARGE CONCENTRATION (mg/ℓ)		AVERAGE SETTLING-POND DISCHARGE CONCENTRATION (mg/ℓ)†
	This Study	Industry	This Study	Industry	
pH	7.4*	7.9*	7.4*	8.0*	8.0*
TSS	10	6	25	8.5	3.4
TDS	225	243	283	291	–
COD	9.7	4.5	13.7	15	–
Oil and Grease	< 1	< 5	<1	< 5	(<10)
Total Fe	< 0.02	–	0.1	–	–
Dissolved Fe	< 0.02	<0.1	< 0.02	<0.1	–
Mn	0.04	< 0.1	< 0.02	<0.1	–
Sulfate	24	–	35	–	–

*Value in pH units

†Historical data

Conditions existing at the mine settling pond should be noted, however. At the mine discharge, an extremely low flow was encountered, and only intermittent pumping of the mine was being employed. At the settling-pond discharge, however, flow conditions were adequate for sampling. Historical data obtained at this location for nine months during 1974 show that a range of 1 to 9 (average of 3.4) mg/l of TSS was encountered after settling.

Mills Employing Physical and/or Chemical Separations. Iron beneficiation plant 1109 uses magnetic separation, coupled with a froth-flotation sequence that removes undesired silica in the iron concentrate. The processing circuit uses 587 cubic meters (155,000 gallons) of water per minute, with a recycle rate of 568 cubic meters (150,000 gallons) per minute. Thickeners, located adjacent to the concentrator, are used to reclaim water close to the site of reuse so as to minimize pumping requirements. Superfloc 16, an anionic polyacrylamide, is added to the thickeners at a rate of 2.5 grams per metric ton (0.0049 pound per short ton) of mill feed to aid in clarification of the water in the thickeners. The thickener underflow is pumped to a 850-hectare (2,100-acre) tailing basin for the sedimentation of the solids. Mine water is also pumped to the basin. The effluent leaves the basin after sufficient retention and flows into a creek at an average rate of 22330 cubic meters (5,900,000 gallons) per day. Chemical analysis of the wastewater to the tailing pond (mine and mill water) in comparison to the effluent water quality and waste loading is given in Table VII-6.

Mills Employing Magnetic and Physical Separation. Mill 1105 is located in the Mesabi Range of Minnesota and is processing ore of the Biwabik formation. Crude magnetic taconite is milled to produce a finely divided magnetite concentrate. The mill's water system is a closed loop having no point-source discharges to the environment. The plant processes use 20.4 cubic meters (54,000 gallons) per minute, with 189 cubic meters (50,000 gallons) per minute returned from the tailing-thickener overflow and 15.1 cubic meters (4,000 gallons) per minute returned from the tailing pond or basin. The tailing thickener accumulates all the milling-process wastewater containing the tailings. A nontoxic polyacrylamide flocculant (SuperFloc 16) is added to the thickener to assist the settling out of solids. Tailing thickener underflow is pumped to a tailing basin of 470 hectares (1,160 acres), where the solids are settled and the clear water is recycled back into the plant water-use system. A simplified water-use sequence is shown in Figure VII-6.

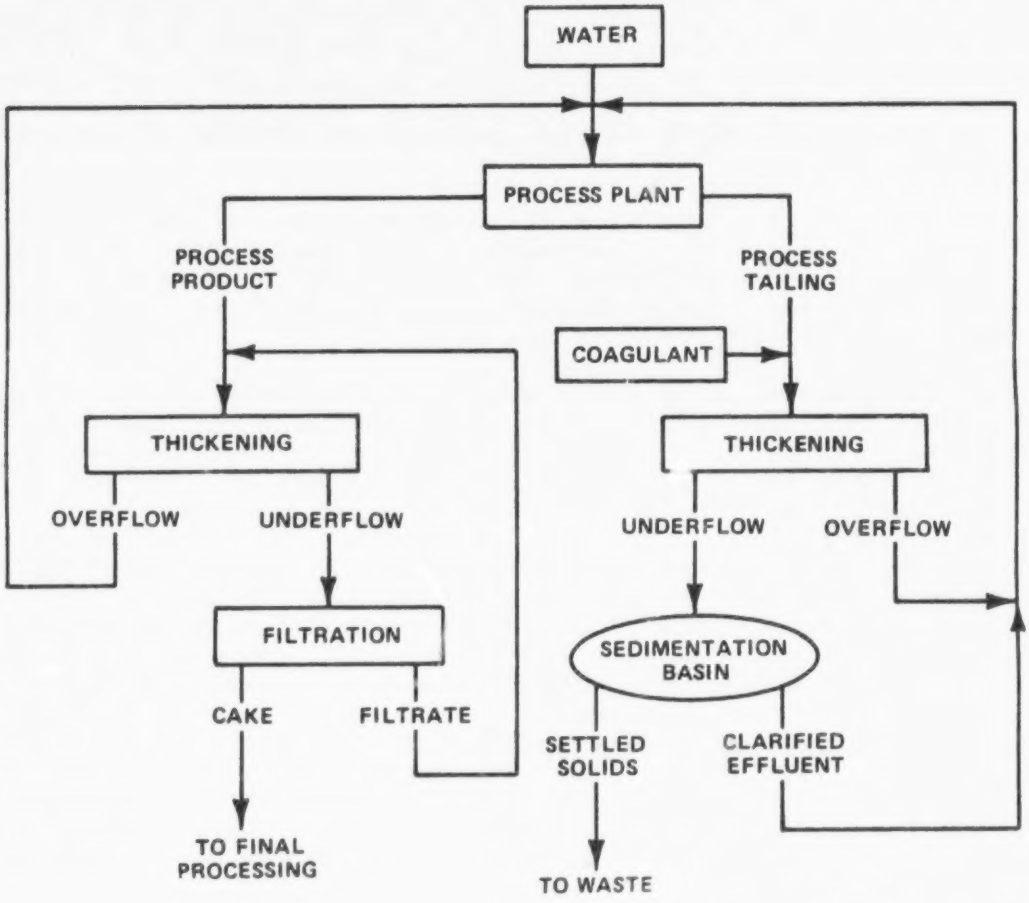
TABLE VII-6. CHEMICAL COMPOSITIONS OF RAW AND TREATED WASTELOADING AT MINE/MILL 1109

PARAMETER	MINE EFFLUENT	MILL EFFLUENT			FINAL DISCHARGE			
	CONCENTRATION (mg/ℓ)	CONCENTRATION (mg/ℓ)	WASTE LOAD PER UNIT PRODUCT		CONCENTRATION (mg/ℓ)	WASTE LOAD PER UNIT PRODUCT		HISTORICAL CONCENTRATION[*] (mg/ℓ)
			kg/metric ton	lb/short ton		kg/metric ton	lb/short ton	
pH	8.3[**]	8.5[**]	–	–	8.3[**]	–	–	7.7[**]
TSS	12	(55%)	1,345	2,690	10	0.02	0.04	3.4
TDS	308	360	0.88	1.76	222	0.48	0.96	–
COD	27.5	13.5	0.033	0.066	18.0	0.039	0.078	–
Total Fe	0.30	0.04	0.0001	0.0002	0.75	0.0016	0.0032	–
Dissolved Fe	0.02	0.04	0.0001	0.0002	0.44	0.0010	0.0020	0.60
Mn	0.65	–	–	–	<0.02	< 0.00004	0.00008	0.06
Sulfate	37	20.7	0.05	0.10	3.5	0.0076	0.0152	–
Alkalinity	181	238	0.58	1.16	120	0.26	0.52	–

[*] Average of nine values (August through October 1974)

[**] Value in pH units.

Figure VII-6. MILL 1105 WATER-USE SYSTEM (ZERO DISCHARGE)


WATER
PROCESS PLANT
PROCESS PRODUCT
PROCESS TAILING
COAGULANT
THICKENING
THICKENING
OVERFLOW
UNDERFLOW
UNDERFLOW
OVERFLOW
FILTRATION
SEDIMENTATION BASIN
CAKE
FILTRATE
SETTLED SOLIDS
CLARIFIED EFFLUENT
TO FINAL PROCESSING
TO WASTE

Copper Ores

The discussion that follows describes treatment and control technology in current use in the five subcategories of the copper-ore mining and dressing industry.

Mining Operations. Mine water generated from natural drainage is reused in mining, leaching, and milling operations wherever possible in the copper mining industry. Because of an excess of precipitation in certain areas of the country, a location which is not proximate to a milling facility, or an inability to reuse the entire amount of mine wastewater at a particular mill, a discharge may result. The amounts of precipitation and evaporation thus have an important influence on the presence or absence of mine-water discharge.

To avoid discharge, mine effluent may be reused in dump, heap, or in-situ leaching as makeup water. As a leach solution, it is acidified (if necessary), percolated through the waste dump, sent through an iron-precipitation facility, and recycled to the dump (Figure VII-7).

Large quantities of water are usually needed in the copper flotation process. Mine-water effluent is used at many facilities as mill process makeup water. The mine water may pass through the process first, or it may be conveyed to the tailing pond, from which it is used for mill flotation with recycled process water (Figure VII-8). The practice of combining mine water with mill water can create water-balance difficulties unless the mill circuit is capable of handling the water volumes generated without a discharge resulting. The discharge of mine water into a mill process system which creates an excess water balance and subsequent discharge may have a detrimental effect on the mine water because of contamination by mill flotation reagents and residual wastes. However, in other instances, a benefit has been realized when mine and mill wastewater is combined for treatment. For this reason, the optimum wastewater-treatment scheme adopted must be determined on an individual basis.

Acid mine water is encountered in the copper mining industry, and methods of neutralization usually employed include the addition of lime and limestone. Acid mine water containing solubilized metals may be effectively treated by combining the mine water with the mill tails in the mill tailings pond. The water may be further treated by lime-clarification and aeration.

Figure VII-7. CONTROL OF EFFLUENT BY REUSE OF MINE WATER IN LEACHING (MINE 2122)

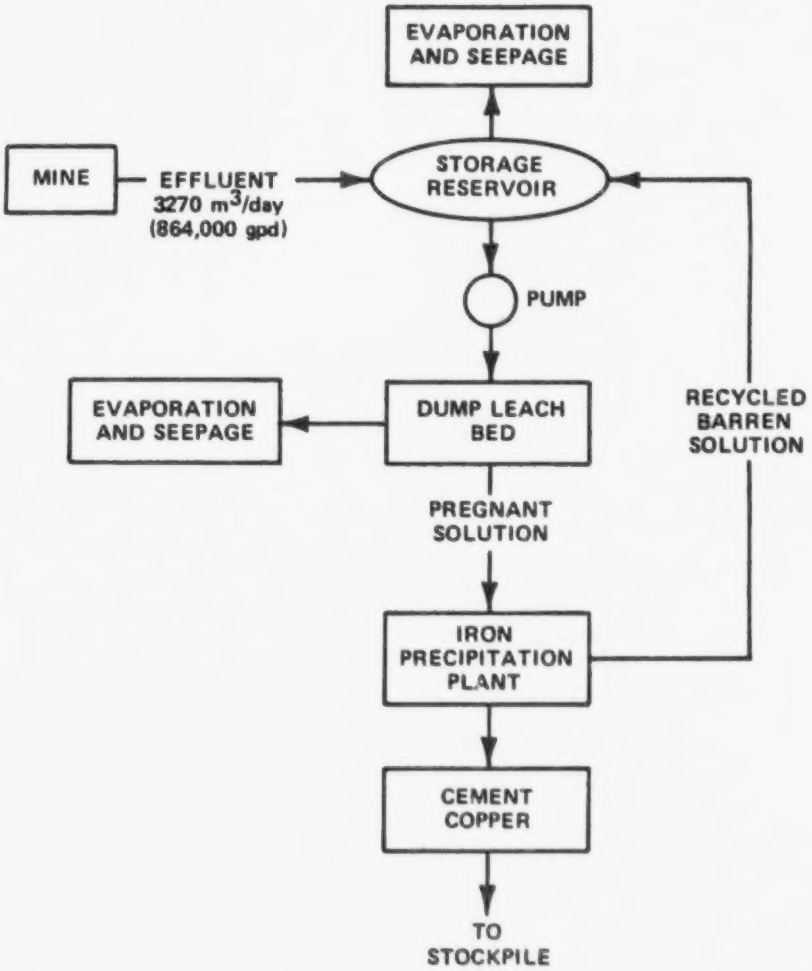
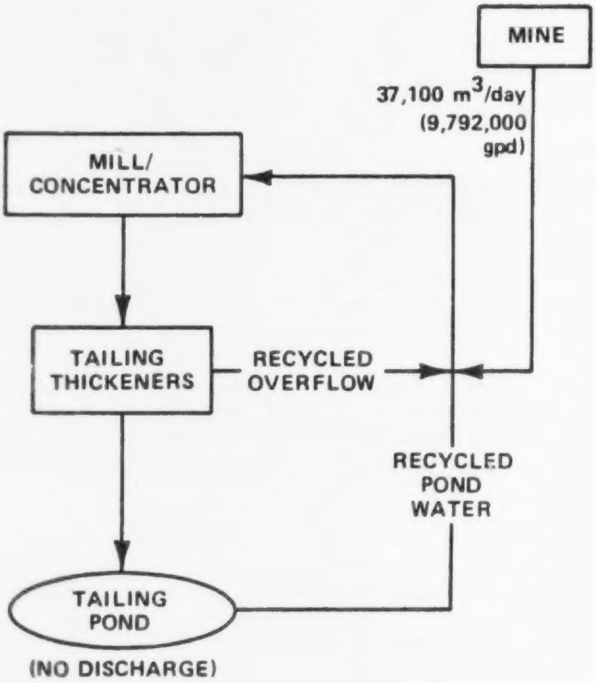

EVAPORATION AND SEEPAGE
MINE
EFFLUENT 3270 m3/day (864,000 gpd)
STORAGE RESERVOIR
PUMP
EVAPORATION AND SEEPAGE
DUMP LEACH BED
RECYCLED BARREN SOLUTION
PREGNANT SOLUTION
IRON PRECIPITATION PLANT
CEMENT COPPER
TO STOCKPILE

Figure VII-8. CONTROL OF MINE-WATER EFFLUENT BY REUSE IN THE CONCENTRATOR (MINE/MILL 2119)


MINE
37,100 m3/day
(9,792,000 gpd)
MILL/ CONCENTRATOR
TAILING THICKENERS
RECYCLED OVERFLOW
RECYCLED POND WATER
TAILING POND
(NO DISCHARGE)

Lime precipitation is also often used to enable the removal of heavy metals from wastewater by precipitation as hydroxides. Tables VII-7 and VII-8 show examples of the use of lime precipitation for treatment of mine water at two locations of mine 2120. The use of this treatment technology is demonstrated to effectively reduce several heavy metals of interest.

Various techniques are employed to augment the use of lime neutralization. Among these are secondary settling ponds, clarifier tanks, or the addition of flocculating agents (such as polyelectrolytes) to enhance removal of solids and sludge before discharge. Often, readjustment of the pH is necessary after lime treatment. This can be accomplished by addition of sulfuric acid or by recarbonation. The use of sulfide precipitation may be necessary in some instances for further removal of metals such as cadmium and mercury.

Mine Employing Hydrometallurgical Process. Acid solutions employed in dump, heap, and in-situ leaching are recycled in this subcategory of the copper industry, allowing the recovery of copper in the iron precipitation plant. Water is added to replace losses due to evaporation and seepage. Acid is added to control pH. Table VII-9 lists the operations surveyed and their control of acid solutions. Only one operation surveyed discharges a small amount of "bleed water" to surface waters.

Control of seepage and collection of acid-leach solution are sometimes aided by the construction of specially prepared surfaces, upon which heaped ores are placed for leaching. These surfaces may be constructed of asphalt, concrete, or plastic.

One facility currently bleeds the acid-leach solution and treats the bleed by neutralization and precipitation with alkaline (limed) tailings from the mill. The treated water flows into the tailing pond for settling and is subsequently recycled with the decant water to the mill.

Treatment of the leach solutions used in this subcategory is sometimes necessary for control of dissolved solids, which build up during recycling. Holding ponds are constructed to retain leach solutions for a sufficient time to allow the iron salts to precipitate from solution and settle, before the solution is recycled to leach beds. In conjunction with, or in place of holding ponds, pH control aids in preventing iron salts from precipitating in pipes or in the leach dump.

TABLE VII-7. CONCENTRATION OF PARAMETERS PRESENT IN RAW WASTEWATER AND EFFLUENT FOLLOWING LIME PRECIPITATION AT MINE 2120B

PARAMETER	CONCENTRATION (mg/ℓ)			
	RAW WASTEWATER (CONTRACTOR DATA†)	TREATED WASTEWATER		
		CONTRACTOR DATA†	COMPANY MONITORING DATA**	
			MEAN	RANGE
pH	6.1 to 10.8*	10.9 to 12.7*	–	–
TDS	2,200	3,000	–	–
TSS	131	32	12	7 to 46
Oil and Grease	< 1	< 1	–	–
Cd	0.13	< 0.04	0.01	< 0.01 to 0.03
Cu	2.6	0.18	0.07	0.04 to 0.61
As	0.02	< 0.02	0.004	0.001 to 0.033
Zn	12	0.35	0.16	0.08 to 1.0
Fe	7.5	0.7	0.11	0.09 to 0.68
Ni	0.13	< 0.05	–	–
Hg	0.0015	0.0007	0.0003	< 0.0002 to 0.0006
Pb	< 0.1	< 0.1	0.01	< 0.01 to 0.01

* Value in pH units.

† Average of one grab sample and two 24-hour composite samples.

** For period June 1975 through May 1976. Mean values are averages of monthly mean data; range is lowest monthly average and highest single-day concentrations observed.

TABLE VII-8. CONCENTRATION OF PARAMETERS PRESENT IN RAW WASTEWATER AND EFFLUENT FOLLOWING LIME PRECIPITATION AT MINE 2120C

PARAMETER	CONCENTRATION (mg/l)			
	RAW WASTEWATER (CONTRACTOR DATA*)	TREATED WASTEWATER		
		CONTRACTOR DATA*	COMPANY MONITORING DATA†	
			MEAN	RANGE
pH	6.9	8.5	–	–
TDS	450	–	–	–
TSS	2,075	26	7	3 to 30
Cu	18	0.14	0.26	0.05 to 0.51
Cd	0.09	< 0.04	0.01	< 0.01 to 0.01
As	0.05	< 0.02	0.004	< 0.001 to 0.011
Zn	5.1	0.21	0.25	0.03 to 0.62
Fe	84	0.46	0.58	0.08 to 1.13
Hg	0.0001	0.0001	0.0003	< 0.0002 to 0.0005
Pb	< 0.1	< 0.1	0.01	< 0.01 to 0.03

* Average of one grab sample (collected October 1974) and two 24-hour composites (collected May 1975).

**Value in pH units.

† For period June 1975 through May 1976. Mean data are averages of single monthly analyses; range data represent range of single monthly analyses.

TABLE VII-9. DUMP, HEAP, AND IN-SITU LEACH-SOLUTION CONTROL AND TREATMENT PRACTICE (1973)

PLANT	CONTROL	TREATMENT	DISCHARGE
2101 2102 2103 2110 2116 2118 2123	Zero discharge	Recycle without treatment	None
2107	Zero discharge	20% to evaporation ponds	None
2108 2122 2124 2125	Zero discharge	All effluent circulated through holding ponds or reservoirs	None
2104	99.4% recycle	None	654 m^3/day (avg)*
2120	98.7% recycle	Bleed is limed and settled in tailing pond	2551 m^3/day (avg)** to tailing pond (not discharged)

*Inadequate pumps. Operation required to attain zero discharge by State Regulations in 1977.

**The treated bleed is recycled to the mill with the decant.

Evaporation ponds are also employed to accomplish zero discharge of acid-leach bleed solutions.

Mill Employing Vat Leaching for Extraction. Zero discharge has been reached by all facilities studied (Table VII-10). Makeup water is required to replace evaporative losses and the moisture which remains in the discarded, leached ores.

Complete recycling of barren leach and wash solutions is usually practiced. However, one facility presently reuses its spent vat-leach solution in a smelter process to achieve zero discharge.

Mill Employing Concentration by Froth Flotation. Mills employing froth flotation could be divided into two subcategories of the copper-ore mining and dressing industry based on climatic conditions such as: (1) mills located in areas where net evaporation is less than 76.2 cm (30 in.); and (2) mills located in areas where net evaporation equals or exceeds 76.2 cm (30 in.). All facilities currently in operation in group (2) discharge no wastewater effluent.

Process water from froth flotation contains large amounts of suspended solids, which are normally directed to a large lagoon to effect settling of these solids. Surface runoff, such as that resulting from snow melt, heavy-rainfall events, streams, and drainage, should be conveyed around the tailing pond, thus preventing runoff water from contacting process effluents. In this manner, the volume of water which must be treated or impounded is reduced.

Mill tailing-pond water may be decanted after sufficient retention time. One alternative to discharge, and an aid to reducing the amount of effluent, is to reuse the water in other facilities as either makeup water or full process water. Usually, some treatment is required for reuse of this decanted water. Figure VII-9 illustrates the control of effluent by reuse, as practiced at mill 2124.

The volume of water to be treated in flotation mills can be effectively reduced, and the quality of the discharge often substantially improved, by the separation of mine water, sewage, smelter drainage, refinery wastes, and leach bleed solution from the tailing-pond circuit. It has been observed that separation of mine water, with subsequent treatment and discharge of the mine water only, can allow mill tailing decant water to be recycled fully. Using mine/mill 2121 as an example, Figure VII-10 was constructed to illustrate current practice, as well as alternative

TABLE VII-10. SOLUTION-CONTROL PRACTICE IN VAT LEACHING OF COPPER ORE

MILL	CONTROL	RECYCLE TREATMENT
2102	100% recycle	None
2116	100% recycle	None
2124	100% recycle	None
2126	Zero discharge	Spent acid sent to acid plant for reuse

Figure VII-9. CONTROL OF EFFLUENT THROUGH REUSE OF MILL FLOTATION-PROCESS WATER IN OTHER FACILITIES (MINE/MILL 2124)

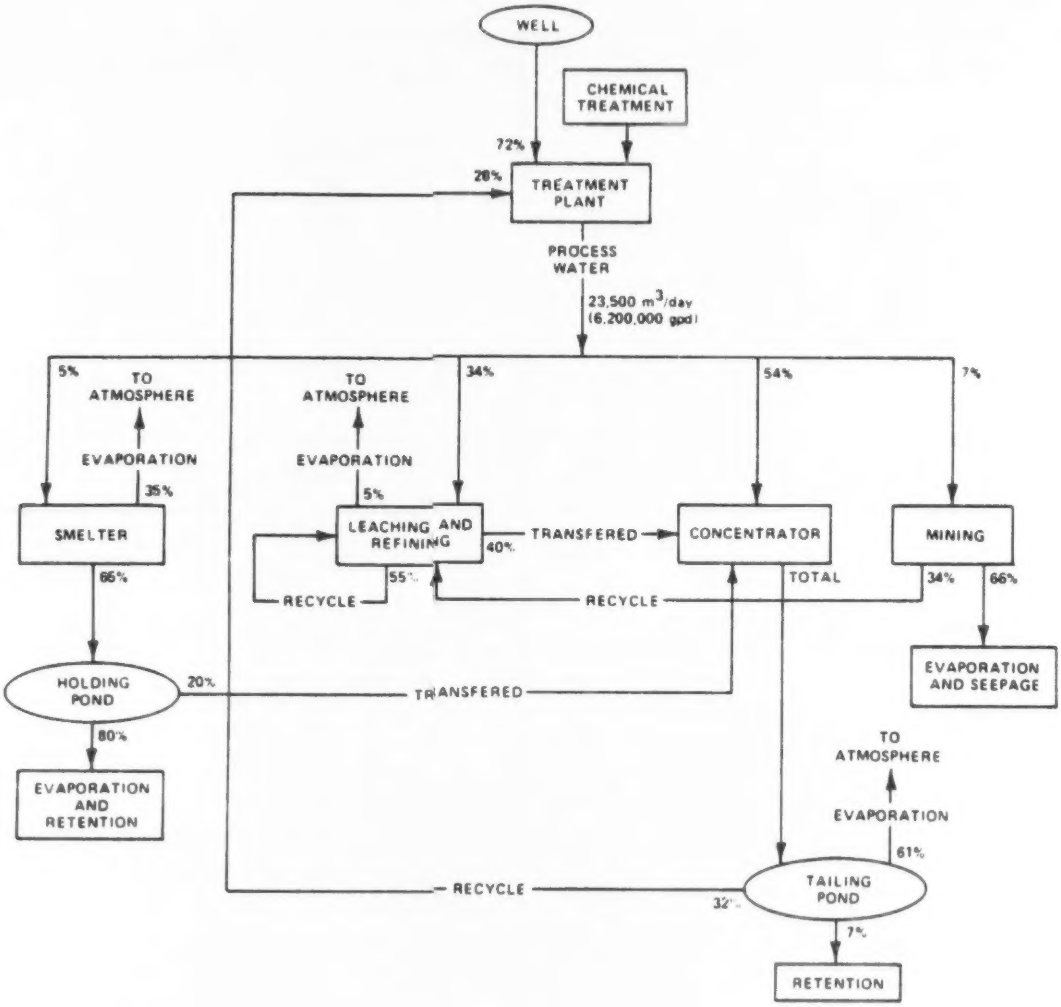
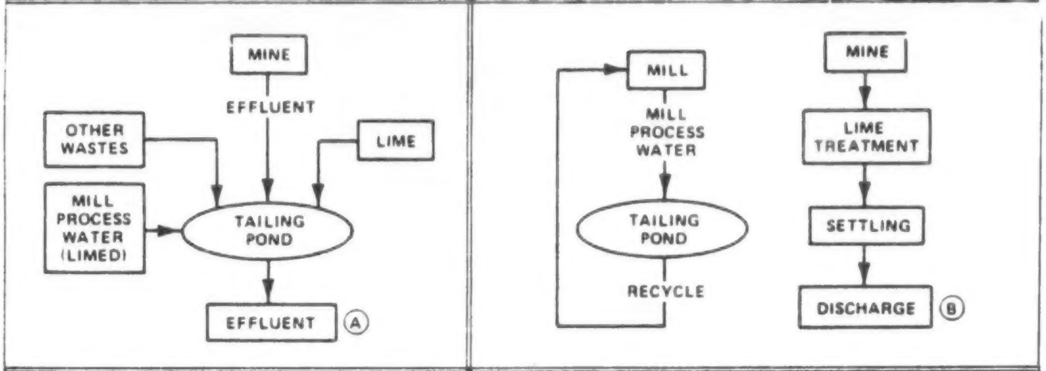

WELL
CHEMICAL TREATMENT
72%
28%
TREATMENT PLANT
PROCESS WATER
23,500 m³/day (6,200,000 gpd)
5%
34%
54%
7%
TO ATMOSPHERE
EVAPORATION
35%
TO ATMOSPHERE
EVAPORATION
5%
SMELTER
LEACHING AND REFINING
40%
TRANSFERED
CONCENTRATOR
MINING
65%
55%
RECYCLE
RECYCLE
TOTAL
34%
66%
HOLDING POND
20%
TRANSFERED
EVAPORATION AND SEEPAGE
80%
EVAPORATION AND RETENTION
TO ATMOSPHERE
EVAPORATION
61%
RECYCLE
32%
TAILING POND
7%
RETENTION

Figure VII-10. REDUCTION IN WASTE POLLUTANT LOAD IN DISCHARGE BY SEPARATION OF MINEWATER FROM TAILING POND FOR SEPARATE TREATMENT (MILL 2121)

CURRENT

ALTERNATIVE


MINE
EFFLUENT
OTHER WASTES
LIME
MILL PROCESS WATER (LIMED)
TAILING POND
EFFLUENT Ⓐ
MILL
MILL PROCESS WATER
TAILING POND
RECYCLE
MINE
LIME TREATMENT
SETTLING
DISCHARGE Ⓑ

TOTAL WASTE LOAD DISCHARGED AT Ⓐ Per 24 hours in kg/day (lb/day)		ESTIMATED TOTAL WASTE LOAD DISCHARGED, USING LIME PRECIPITATION, AT Ⓑ Per 24 hours in kg/day (lb/day)		
			Raw (No Treatment)	After Treatment
Flow	102,000 m^3/day (27,000,000 gpd)	Flow	3,800 m^3/day (1,000,000 gpd)	3,800 m^3/day (1,000,000 gpd)
pH	8.4*	pH	7.4*	12.7*
TSS	620 (1,364)	TSS	267 (587)	129 (284)
Oil and Grease	415 (913)	Oil and Grease	<4 (< 8.8)	< 4 (< 8.8)
Cu	27 (59.4)	Cu	4 (8.8)	0.2 (0.44)
As	<8 (< 17.6)	As	< 0.3 (< 0.66)	< 0.3 (< 0.66)
Zn	5.2 (11.4)	Zn	10.8 (23.8)	0.4 (0.88)
Fe	10.3 (22.7)	Fe	< 0.4 (< 0.88)	< 0.4 (< 0.88)
Cd	< 2 (< 4.4)	Cd	< 0.07 (< 0.154)	< 0.02 (< 0.044)
Ni	< 5.2 (< 11.4)	Ni	< 0.2 (< 0.44)	< 0.2 (< 0.44)
Hg	< 0.01 (< 0.022)	Hg	< 0.0005 (< 0.00110)	0.0004 (0.00088)
Pb	<10.3 (< 22.7)	Pb	< 0.4 (< 0.88)	< 0.4 (< 0.88)

*Value in pH units.

future practice which would result in a reduction of the waste loads discharged.

Separation of mine water and other wastes from contact with mill process water is suggested in all cases where pollutant load and water volume are factors. Not only do these waste waters contribute to the pollutants present in the tailing-pond water, but they may dilute the water to be treated or cause excess water-volume conditions to result which cannot be handled by recycling.

If sewage plant overflow contributes to the tailing-pond water volume to the extent that it cannot be accommodated in recycling, this water should be properly treated and handled separately.

Smelter and refinery wastes often contribute a heavy load of dissolved metals to tailing ponds. These wastes can affect the quality of the decant water, as well as effluent volumes. It may be necessary to handle wastes from these sources separately, and/or as recommended under the appropriate conditions for the Effluent Limitation Guidelines for the Copper Smelting and Refining Industry.

The most efficient control of the volume and pollutant discharge of mill flotation-process water is to recycle the excess water which would overflow from the tailing-pond decant area. Of the 27 major copper mills surveyed, 24 are known to be recycling all or a portion of their process water. The impetus for recycling has often been the lack of an adequate water supply. However, the feasibility of recycling process water appears to have been considered at all facilities.

Through the use of diversion ditching, evaporation (when available), reservoirs, and separation of other process water, the volume of water to be recycled can be adjusted to allow reuse. Treatment of the recycled water is usually required and may include secondary settling, phosphate or lime addition (for softening), pH adjustment, or aeration.

The majority of copper mills currently operating recycle their mill process water. Of the remaining facilities that currently discharge, half are recycling at least 35 percent of their process water. Treatment of discharged water consists of settling alkaline wastewater in a tailing pond. A variety of treatment approaches are currently used in this subcategory, including:

(1) Settling Only
(2) Lime Precipitation and Settling
(3) Lime Precipitation, Settling, Use of Polyelectrolytes, and Secondary Settling

One operation is currently building a treatment facility which will include lime precipitation, settling, and aeration.

Table VII-11 shows the reduction of pollutant concentrations attained in six mills under different conditions of recycling, lime addition, and settling. A wide variation in practice is used to obtain varying degrees of concentration for waste constituents present in treated wastewater. It must be noted that only mills 2120, 2121 and 2122 discharge; the other three mills are achieving zero discharge through recycle. When the data was obtained, mill 2120 was in the process of eliminating discharges from the mill; to date this facility is achieving approximately 90% recycle. Mill 2122 is not providing exemplary treatment.

An exemplary demonstration of waste effluent treatment by lime precipitation is summarized below. In this system, three waste streams enter for combined treatment in a tailing lagoon in the ratio shown. Calculations were based on waterflow volume.

	(mg/l) Mill 2120 Wastewater Sources			Calculated Combined Levels* (mg/l)	After Treatment** (mg/l)	
Parameter	(1)*	(2)*	(3)*		Mean	Range
Volume Ratio	4.2	1	16.2			
TSS	4	14	282,000	>282,000	8	2-96
Cd	0.33	7.74	3.0	2.7	0.019	<0.01-0.04
Cu	92.0	36.0	400	324	0.04	<0.03-0.25
Pb	<0.1	0.1	21	16	<0.01	<0.01
Zn	172	940	310	300	0.10	0.02-0.96
Hg	0.0784	0.0009	0.003	0.015	0.0002	<0.0002-0.0003
Fe	2000	2880	18,800	14,500	0.14	0.06-1.0

Wastewater Source
1 - Acid Mine Water
2 - Spent Leach Solution
3 - Mill Tailing
*Contractor Sampling Data
**Company and Contractor Data Range

Table VII-11. REDUCTION OF POLLUTANTS IN CONCENTRATOR TAILS BY SETTLING AT VARIOUS pH LEVELS

PARAMETER	CONCENTRATION (mg/l)											
	MILL 2120						MILL 2121			MILL 2122		
	RAW WASTEWATER (CONTRACTOR DATA*)	TREATED WASTEWATER					RAW WASTEWATER (CONTRACTOR DATA*)	TREATED WASTEWATER (CONTRACTOR DATA*)	RAW WASTEWATER (CONTRACTOR DATA**)	TREATED WASTEWATER		
		CONTRACTOR DATA*	COMPANY MONITORING DATA††							CONTRACTOR DATA**	(COMPANY MONITORING DATA††)	
			NOVEMBER 1972 JUNE 1975		OCTOBER 1975 MAY 1976						OCTOBER 1975 MAY 1976	
			MEAN	RANGE	MEAN	RANGE					MEAN	RANGE
pH	8.1†	5.8†	8.5†	6.3 TO 11.5†	-	-	9.2†	9.2†	8.5†	8.2†	7.84†	6.0 TO 8.9†
TSS	299,000	71	27	2.7 TO 138	8	2 TO 86	114,000	16.6	312,000	27	26.6	9.7 TO 61
TDS	-	-	-	-	-	-	-	-	-	-	4,185	3,020 TO 5,332
As	<0.02	<0.02	-	-	0.003	<0.001 TO 0.013	-	-	-	-	-	-
Cd	3.0	0.06	0.014	0.003 TO 0.04	0.019	0.01 TO 0.04	0.08	<0.04	0.00	<0.04	0.01	<0.01 TO 0.02
Cu	400	1.26	0.21	0.03 TO 0.65	0.04	<0.03 TO 0.25	152	0.06	147	0.14	0.13	0.04 TO 0.28
Fe	18,800	4.2	-	-	0.14	0.06 TO 1.0	7,680	3.2	550	0.85	0.22***	0.01 TO 0.79***
Hg	0.003	0.004	0.0002	<0.0001 TO 0.0011	0.0002	<0.0002 TO 0.0003	0.005	0.002	0.001	0.001	-	-
Pb	21	<0.1	<0.07	-	<0.01	<0.01	<0.1	<0.1	2.4	<0.1	0.10	0.01 TO 0.41
Zn	310	20.2	0.47***	0.02 TO 1.68**	0.10	0.02 TO 0.96	10.5	<0.05	4.8	0.13	0.16****	0.01 TO 0.78****
Cyanide	0.01	0.03	-	-	-	-	0.02	<0.01	0.17	<0.01	0.046	<0.01 TO 0.37

*Average of two 24 hour composite samples collected May 1976

**Average of two 24 hour composite samples collected June 1975

†Value in pH units

***High value of 32.4 mg/l for sample collected November 1972 excluded

††Mean values are unweighted averages of monthly mean data; range is lowest monthly average and highest single-day concentrations observed

****Analysis of tailing-pond recycle water. No monitoring data available for Fe or Zn in discharged wastewater

Additional treatment of wastewater by polyelectrolyte addition, to reduce suspended solids in tailing-pond discharge, is also practiced at one mill. Secondary settling ponds are used to settle the treated solids prior to discharge.

The effectiveness of the use of coagulants (polymers) is demonstrated in Table VII-12. These data, obtained from a pilot operation, indicate effective reductions of copper, iron, and cobalt, with substantial reductions of aluminum and manganese.

Recycling of process water from the tailing pond has not been difficult for most copper mills surveyed employing this technique. However, treatment of the pond water has been necessary for selected problems encountered. Potential problem areas present at these operations include buildup of scale deposits, pH changes in the tailing pond or in makeup water, and presence of flotation reagents in the recycled water. Effective methods of treatment to alleviate these conditions are phosphate treatment (softening) for scale control, adjustment of pH by liming, and the use of aeration or secondary settling ponds to assist in degradation of flotation reagents.

Lead and Zinc Ores

A discussion of the treatment and control technologies currently employed in the lead and zinc ore mining and dressing industry is included in this section. Two subcategories are represented: Mines and lead or zinc mills.

Mines With Alkaline Drainage Not Exhibiting Solubilization of Metals. The operations generally employ treatment by impoundment in tailing or sedimentation ponds. Mine 3105 (producing lead/zinc/copper concentrates) is located in Missouri. The mine recovers galena (PbS), sphalerite (ZnS), and chalcopyrite (CuFeS). Production began in 1973, and the operation was expected to produce 997,700 metric tons (1,100,000 short tons) of ore in 1974.

The water pumped from this mine is treated by sedimentation in an 11.7-hectare (29-acre) pond. The average mine drainage flow rate is 8,300 [illegible] gallons) per day. The effluent from this basin [illegible] nearby surface stream. The chemical characteristics of the wastewater before and after treatment are presented in Table VII-13, together with data for nine months of 1974. The

TABLE VII-12. EFFICIENCY OF COAGULATION TREATMENT TO REDUCE POLLUTANT LOADS IN COMBINED WASTE (INCLUDING MILL WASTE) PRIOR TO DISCHARGE (PILOT PLANT – MILL 2122, NOVEMBER 1974)

POLLUTANT PARAMETER	WASTE LOAD IN INFLUENT TO PROCESS		WASTE LOAD IN EFFLUENT TO DISCHARGE		% EFFICIENCY IN REMOVAL
	kg/1000 metric tons	lb/1000 gal	kg/1000 metric tons	lb/1000 gal	
Flow	75,134 m^3/day	19,850,400 gpd	75,198 m^3/day	19,866,240 gpd	–
pH	7.5*	7.5*	9.0*	9.0*	–
TDS	3,500	6	3,900	7	–
TSS	10	0.02	14	0.02	–
Al	2.3	0.004	< 1	< 0.002	> 57%
As	0.2	0.0003	0.9	0.002	–
Cd	< 0.05	< 0.00009	< 0.05	< 0.00009	–
Cu	9.8	0.02	0.9	0.002	90%
Fe	120	0.21	0.7	0.001	> 99%
Pb	3.3	0.006	2.8	0.005	15%
Mn	0.4	0.0007	0.1	0.0002	71%
Hg	0.0001	0.0000001	0.0003	0.0000005	–
Ni	< 0.1	< 0.0002	< 0.1	< 0.0002	–
Co	9.8	0.02	0.9	0.002	90%
Zn	< 0.05	< 0.00009	< 0.05	< 0.00009	–

*Value in pH units

TABLE VII-13. CHEMICAL COMPOSITIONS OF RAW AND TREATED MINEWATERS FROM MINE 3105 (HISTORICAL DATA PRESENTED FOR COMPARISON)

PARAMETER	CONCENTRATION (mg/ℓ)			
	RAW MINE DRAINAGE*	DISCHARGE*	DISCHARGE (HISTORICAL)†	
			AVERAGE	RANGE
pH	7.4**	8.1**	7.8**	7.4** to 8.1**
Alkalinity	196.0	162.0	–	–
Hardness	330.4	173.2	–	–
TSS	138	< 2	3.4	< 1 to 9
TDS	326	204	–	–
COD	<10	< 10	–	–
TOC	< 1.0	3.0	–	–
Oil and Grease	29.0	17.0	1.9	< 1 to 5
P	0.030	0.032	–	–
Ammonia	< 0.05	< 0.05	–	–
Hg	0.0001	< 0.0001	–	–
Pb	0.3	0.1	0.050	0.011 to 0.12
Zn	0.03	< 0.02	0.032	0.008 to 0.11
Cu	< 0.02	< 0.02	< 0.005	<0.050 to 0.070
Cd	< 0.002	0.005	< 0.005	(< 0.005)
Cr	< 0.02	< 0.02	–	–
Mn	< 0.02	0.35	–	–
Fe	< 0.02	0.11	0.086	0.033 to 0.21
Sulfate	63.5	45.5	–	–
Chloride	57	44.5	–	–
Fluoride	1.2	1.0	–	–

*Analysis of single 4-hour composite sample

†Monthly analysis over January 1974 through September 1974

**Value in pH units

treatment sequence is as follows: mine pumping, followed by clarification basin, followed by discharge (8,300 cubic meters (2,190,000 gallons) per day). Relatively simple treatment employed for mine waters exhibiting chemical characteristics similar to mine 3105 can result in attainment of low discharge levels for most constituents. Reduction of parameters such as total dissolved solids, oil and grease, chloride, sulfate, lead, and zinc--as well as excellent reduction of total suspended-solid concentrations--is obtained by this treatment method.

Mine Drainage (Acid or Alkaline) Exhibiting Solubilization of Metals. The characteristics of wastewater from these mines are such that treatment must be applied to prevent the discharge of soluble metals, as well as suspended solids. The treatment practice, as currently employed, involves chemical (often, lime) precipitation and sedimentation.

Mine wastewaters are often treated by discharge into a pond or basin in which the pH is controlled. An approach often used is to discharge the mine wastewater into a mill tailing pond, where wastewater is treated at a pH range which causes the precipitation of the heavy metals as insoluble hydroxides. The presence of residual solids from the milling process is thought to provide nucleation sites for the precipitation of the hydroxides. In cases where ferrous iron is present, it is desirable to cause the oxidation to the ferric form and, thus, to avoid the potential for acid formation by processes similar to the reactions forming acid mine drainage. Vigorous aeration of the wastewater can accomplish oxidation, usually after addition of the pH-adjusting agent.

The treatment process described is similar to the type of pH control, and subsequent physical treatment, usually associated with froth-flotation recovery of sulfides of lead, zinc, and copper (which is followed by sedimentation of the tailings). The milling process itself is, therefore, an analog for a process of treating mine wastes in this subcategory.

Mine 3101 is an underground mine, located in Maine. The mine recovers sphalerite and the byproducts chalcopyrite, galena, and pyrite which are present in the formation. The mine began production 1972 and produced 208,610 metric tons (230,000 short tons) of ore in 1973.

The water pumped from the mine, 950 cubic meters (250,000 gallons) per day, is treated by mixing it with mill tailing discharge, plus additional lime as required for pH control, in a reservoir with a capacity of 37.85 cubic meters (10,000 gallons). The combined waste is then pumped to a 25-hectare (62-acre) tailing pond. The discharge from the tailing pond is sent to an auxiliary pond. The combined retention time in the two ponds is 35 days at maximum flow. Water is recycled for the process from the auxiliary pond, and the excess is discharged. The chemical characteristics of the mine water and the final discharge, treated in the above manner, are given in Table VII-14.

A pilot treatment plant has been operated at a mi[illegible] in New Brunswick, Canada to develop and demonstrate [illegible] existing technology for the removal of heavy metals [illegible] base metal mining effluents. Three mine waters, characterized as strong, weak and moderately strong, have been evaluated and the results published (Reference 71).

The pilot plant design included provisions for two-stage lime additions, flocculation, clarification, filtration, and sludge recycle. The preliminary conclusion (Reference 71) is that the optimum treatment configuration for the three mine waters consists of a once-through operation using polymer and two-stage neutralization (precipitation). Two-stage neutralization was chosen rather than single-stage, even though results demonstrated they are equivalent, as the former is thought to be better able to respond to neutralization load changes.

The mine water characteristics and attainable metal effluent concentrations are given in Table VII-15.

Lead and/or Zinc Mills. As discussed in Section V, the wastewater from lead/zinc flotation mills differs from mine water in that a number of reagents are added to effect the separation of the desired mineral or minerals from the host rock. These waste streams also contain finely ground rock, as well as minerals, as a result of grinding to allow liberation of the desired minerals during the froth-flotation process.

The most common treatment method in use in the lead/zinc-milling industry is the tailing or sedimentation pond. Often considered a simple method of treatment, properly designed tailing ponds perform a number of important functions simultaneously. Some of these functions include removal of tailing solids by sedimentation, formation of metal precipitates, long-term retention of settled tailings and precipitates, stabilization of oxidizable constituents,

TABLE VII-14. CHEMICAL COMPOSITION OF RAW AND TREATED MINEWATER FROM MINE 3101

PARAMETER	CONCENTRATION (mg/ℓ)		
	RAW MINE WATER (CONTRACTOR DATA*)	TREATED DISCHARGE (COMPANY MONITORING DATA†)	
		MEAN	RANGE
pH	7.0**	8.0**	7.1 to 10.8**
TSS	1047	10††	–
Cd	0.08	0.005	< 0.001 to 0.024
Cu	2.1	0.019	0.002 to 0.133
Pb	1.9	0.024	0.004 to 0.16
Zn	22.9	0.13	0.03 to 0.466
Cr	0.012	0.007	< 0.002 to 0.038
Fe	22.0	0.30	0.026 to 1.498
Mn	1.7	0.066	0.004 to 0.266

* Average of six 24-hour composite samples.

† For period October 1974 through September 1975. Mean values are averages of monthly mean data; range's lowest monthly average and highest single-day concentrations observed.

**Value in pH units.

†† From NPDES Permit Application data.

TABLE VII-15. CHEMICAL CHARACTERISTICS OF RAW AND TREATED MINE WATERS FOR NEW BRUNSWICK, CANADA, COPPER/LEAD/ZINC PILOT-PLANT OPERATION

PARAMETER	CONCENTRATION (mg/l)																	
	MINE 1						MINE 2						MINE 3					
	RAW MINE WATER		TREATED DISCHARGE				RAW MINE WATER		TREATED DISCHARGE				RAW MINE WATER		TREATED DISCHARGE			
			ALL TESTS		STEADY OPERATION				ALL TESTS		STEADY OPERATION				ALL TESTS		STEADY OPERATION	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
pH	–	2.4 to 3.2*	–	–	–	–	–	2.8 to 3.3*	–	–	–	–	–	2.3 to 2.9*	–	–	–	–
Pb†	4.3	0.9 to 8.0	0.12	0.07 to 0.18	0.15	0.14 to 0.15	1.3	0.1 to 5.0	0.31	0.01 to 0.50	0.29	0.17 to 0.42	1.2	0.3 to 3.0	0.10	0.05 to 0.35	0.08	0.05 to 0.22
Zn†	1160	735 to 1590	0.26	0.14 to 0.39	0.39	0.38 to 0.39	100	22 to 175	0.29	0.03 to 0.58	0.15	0.03 to 0.29	540	300 to 723	0.21	0.01 to 0.75	0.12	0.03 to 0.18
Cu†	10	15 to 17	0.03	0.02 to 0.04	0.03	0.03	20	12 to 52	0.03	0.02 to 0.04	0.03	0.02 to 0.03	50	24 to 76	0.04	0.01 to 0.30	0.03	0.02 to 0.04
Fe†	1580	815 to 3210	0.23	0.05 to 0.63	0.20	0.14 to 0.26	60	24 to 230	0.11	0.02 to 0.70	0.13	0.11 to 0.17	720	350 to 1290	0.22	0.01 to 0.80	0.14	0.08 to 0.23

*Values in pH units

†Extractable or total metal

Source of data: Reference 71

and balancing of influent-water quality and quantity of flow.

In the lead/zinc-ore milling industry, a biological treatment method, used in conjunction with stream meanders, was observed at one location. This treatment method has been described in the previous discussion in this section.

The ability to recycle the water in lead/zinc flotation mills is affected by the buildup of complex chemical compounds (which may hinder extraction metallurgy) and sulfates (which may cause operating problems associated with gypsum deposits). One solution to these problems is a cascade pond system. There, the reclaimed water from thickeners, filters, and tailing ponds may be matched with the requirements for each point of the circuit (Reference 72).

In another study (Reference 73), the many operational problems associated with the recycling of mill water are described in detail. The researchers have observed that recycling at the operations studied had not caused any unsolvable metallurgical problems and, in fact, indicate that there are some economic benefits to be gained through decreasing the amounts of flotation reagents required.

Mill 3103 is located in Missouri and recovered galena, sphalerite, and chalcopyrite from 846,000 metric tons (934,000 short tons) of ore in 1973.

The mill utilizes both mine water and water recycled from the tailing pond as feed water. The concentrator discharges 9,500 cubic meters (2,150,000 gallons) per day of tailing slurry to its treatment facility. The treatment facility utilizes a 42.5-hectare (105-acre) tailing pond with estimated retention of 72 days, a small stilling pond at the base of the tailing-pond dam, and a shallow 6.1-hectare (15-acre) polishing pond before discharge. A schematic diagram of average daily water flows for the facility is given in Figure VII-11. Effluent chemical composition and waste load discharged at mill 3103 using the above treatment are given in Table VII-16.

Mill 3102 is located in Missouri. This mill processed approximately 1,450,000 metric tons (1,600,000 short tons) of ore in 1973. Galena and sphalerite are recovered as concentrates at this operation.

Figure VII-11. SCHEMATIC DIAGRAM OF WATER FLOWS AND TREATMENT FACILITIES AT MILL 3103

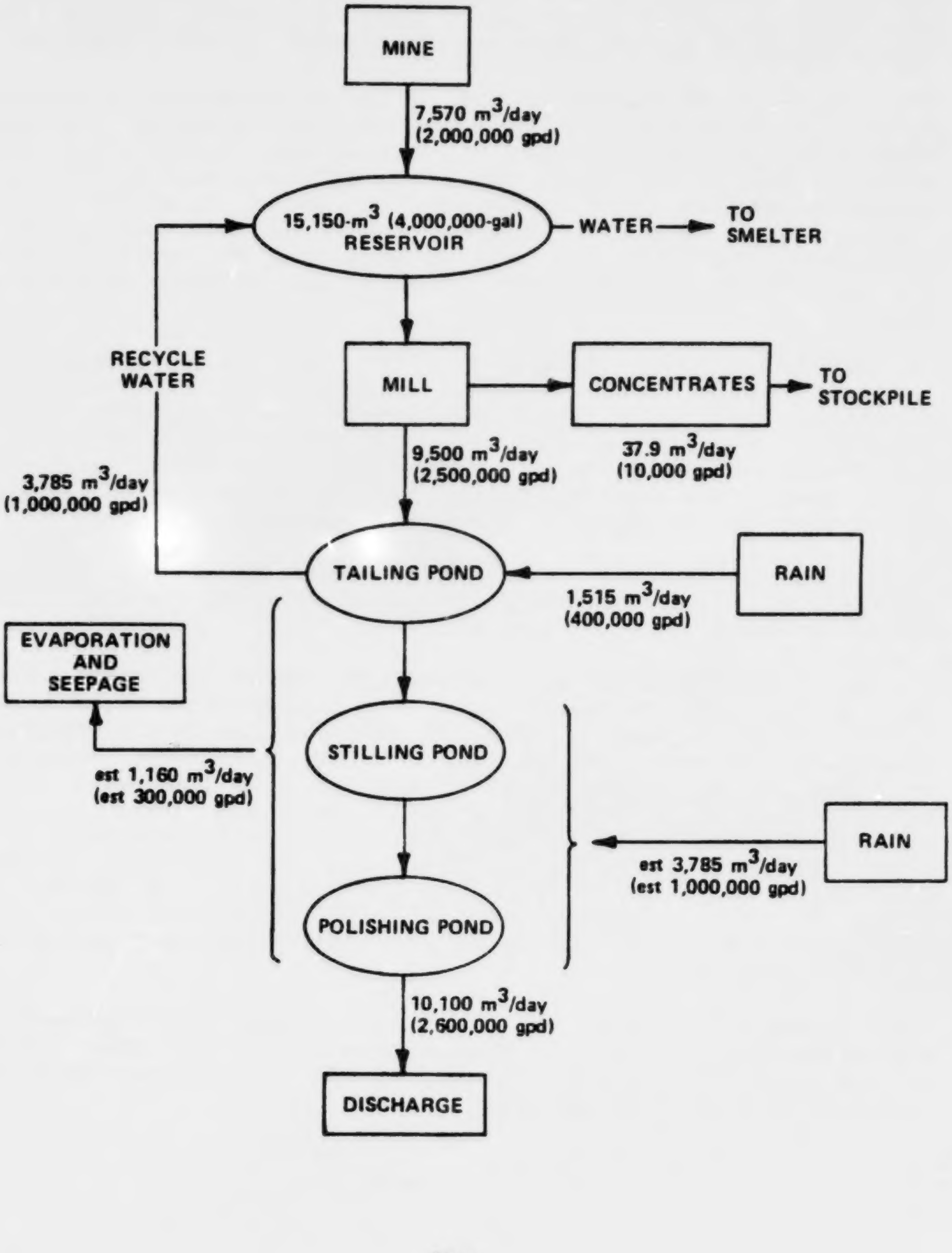

MINE
7,570 m³/day
(2,000,000 gpd)
15,150-m³ (4,000,000-gal) RESERVOIR
WATER
TO SMELTER
RECYCLE WATER
MILL
CONCENTRATES
TO STOCKPILE
9,500 m³/day
(2,500,000 gpd)
37.9 m³/day
(10,000 gpd)
3,785 m³/day
(1,000,000 gpd)
TAILING POND
RAIN
1,515 m³/day
(400,000 gpd)
EVAPORATION AND SEEPAGE
est 1,160 m³/day
(est 300,000 gpd)
STILLING POND
RAIN
est 3,785 m³/day
(est 1,000,000 gpd)
POLISHING POND
10,100 m³/day
(2,600,000 gpd)
DISCHARGE

TABLE VII-16. CHEMICAL COMPOSITION AND WASTE LOAD OF TREATED MILL WASTEWATER AT MILL 3103

PARAMETER	CONCENTRATION (mg/ℓ)		EFFLUENT WASTE LOAD per unit ore milled	
	THIS PROGRAM*	HISTORICAL†	kg/1000 metric tons	lb/1000 short tons
pH	7.8**	7.9**	–	–
TSS	16	1.4	40	80
COD	726	–	1,700	3,400
Oil and grease	3.0	–	7	14
Cyanide	< 0.01	N/A	0.024	0.048
Hg	< 0.0001	–	0.00024	< 0.00048
Pb	0.1	0.028	0.24	0.48
Zn	0.07	0.045	0.168	0.336
Cu	< 0.02	0.006	< 0.048	< 0.096
Cd	< 0.002	< 0.001	< 0.005	< 0.010
Cr	< 0.02	0.001	< 0.048	< 0.096
Mn	0.05	0.074	0.12	0.024
Total Fe	0.09	0.032	0.282	0.564

*Data based on 4-hour composite samples

†Data average over period January through October 1974

**Value in pH units

N/A = Not Available

The mill utilizes mine water exclusively as feed. It discharges 15,150 cubic meters (4,000,000 gallons) per day of tailing slurry to a large tailing pond. This pond also receives about 3,785 cubic meters (1,000,000 gallons) per day of excess mine water and another 3,785 cubic meters (1,000,000 gallons) per day of surface-drainage water. This tailing pond presently occupies 32.4 hectares (80 acres) and will occupy 162 hectares (400 acres) when completed to design. The tailing-pond decant water is discharged to a small stilling pool and then enters a meander system, where biological treatment occurs. An additional sedimentation basin of approximately 6.1 hectares (15 acres), for removal by sedimentation of any algae which breaks loose from the meander system, has been constructed near the end of the meander system for use just before final discharge. A schematic diagram of the mill operation and the treatment facility is presented in Figure VII-12.

Water characteristics for the effluent from the mill, the overflow from the tailing pond, and the final discharge treated utilizing the above technology are presented in Table VII-17.

Mill 3105 is located in Missouri and recovered galena, sphalerite, and chalcopyrite from an estimated 997,000 metric tons (1,100,000 short tons) of ore in 1974.

This mill utilizes water recycled from its tailing-pond system and makeup water from its mine as feed water. The mill discharges 7,910 cubic meters (2,090,000 gallons) per day of wastes to a 11,8-hectare (29-acre) tailing pond. The decant from this pond is pumped to an 7.3-hectare (18-acre) reservoir, which also receives the required makeup water from the mine. The mill draws all its feed water from this reservoir. No discharge occurs from the mill.

A schematic diagram of the water flows and treatment facilities is presented in Figure VII-13.

Mill 3101 is located in Maine and recovered sphalerite and chalcopyrite from 208,000 metric tons (230,000 short tons) of ore in 1973.

This mill utilizes only water recycled from its treatment facilities as feed water. The mill discharges to a mixing tank, where mine water is treated by chemical precipitation that is achieved by combining with the tailing slurry and liming as required. This combined waste is introduced into a tailing pond, which discharges to an auxiliary pond. The

Figure VII-12. SCHEMATIC DIAGRAM OF WATER FLOW AND TREATMENT FACILITIES AT MILL 3102 (TAILING POND/STILLING POND/ BIOLOGICAL TREATMENT/POLISHING POND)

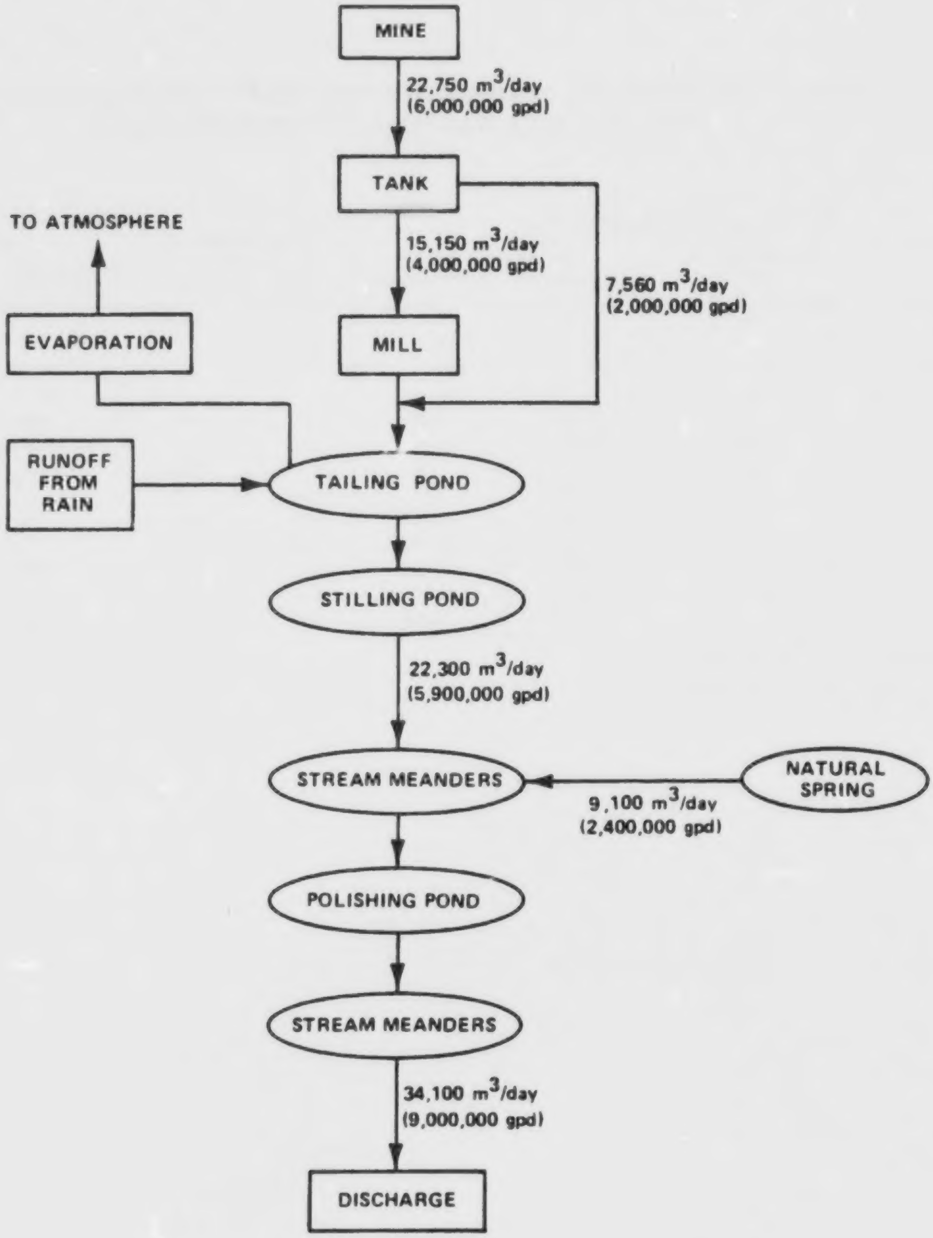

MINE
22,750 m3/day
(6,000,000 gpd)
TANK
TO ATMOSPHERE
15,150 m3/day
(4,000,000 gpd)
7,560 m3/day
(2,000,000 gpd)
EVAPORATION
MILL
RUNOFF FROM RAIN
TAILING POND
STILLING POND
22,300 m3/day
(5,900,000 gpd)
STREAM MEANDERS
NATURAL SPRING
9,100 m3/day
(2,400,000 gpd)
POLISHING POND
STREAM MEANDERS
34,100 m3/day
(9,000,000 gpd)
DISCHARGE

TABLE VII-17. CHEMICAL COMPOSITION AND WASTE LOADING FOR RAW AND TREATED MILL WASTEWATER FROM MILL 3102

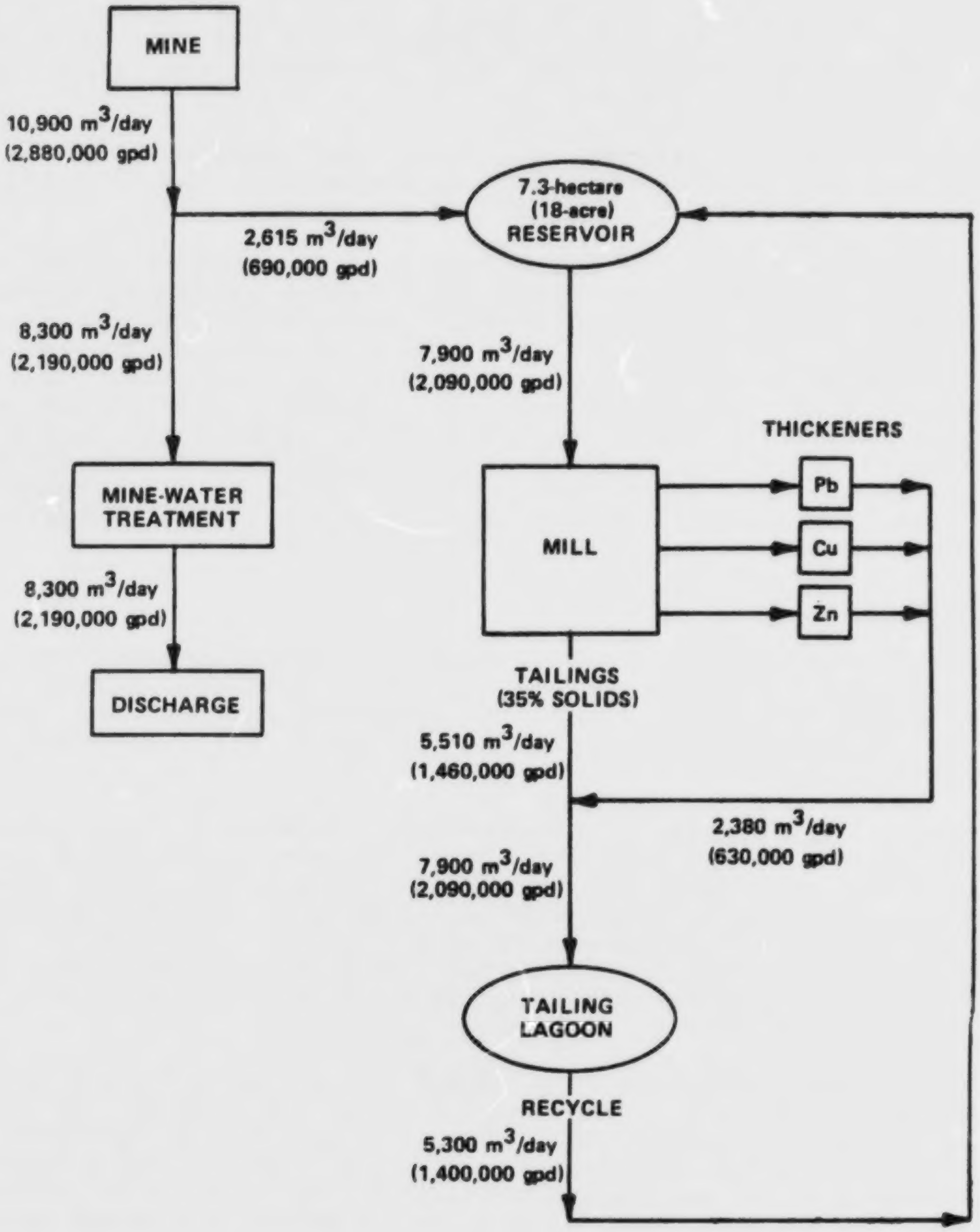
PARAMETER	TAILING POND DECANT			FINAL DISCHARGE			
	CONCENTRATION (mg/ℓ)*	WASTE LOAD per unit ore milled		CONCENTRATION (mg/ℓ)		WAS[illegible]OAD per uni[illegible] milled	
		kg/1000 metric tons	lb/1000 short tons	THIS PROGRAM*	HISTORICAL†	kg/1000 metric tons	lb/1000 short tons
pH	7.8**	–	–	7.6**	7.9**	–	–
TSS	16	464	928	8	2	66	132
COD	563.5	1,600	3,200	11.9	–	98	196
Oil and Grease	6.0	174	348	3.0	–	25	50
Cyanide	< 0.01	< 0.029	< 0.058	< 0.01	< 0.01	0.082	< 0.174
Hg	< 0.0001	< 0.0003	< 0.0006	< 0.0001	–	< 0.0003	< 0.0006
Pb	0.35	1	2	< 0.1	0.002	0.25	0.50
Zn	0.29	0.84	1.68	0.04	0.005	0.1	0.2
Cu	< 0.02	< 0.058	< 0.116	< 0.02	0.001	< 0.05	< 0.1
Cd	0.002	0.0058	< 0.0116	0.005	< 0.001	< 0.013	< 0.026
Cr	< 0.02	< 0.058	< 0.116	< 0.02	–	< 0.058	< 0.116
Mn	0.28	0.81	3.162	0.16	–	0.4	0.8
Total Fe	0.16	0.464	0.928	0.13	0.003	0.325	0.65

*Data based on 4-hour composite samples

†Data average over period January through September 1974

**Value in pH units

Figure VII-13. SCHEMATIC DIAGRAM OF WATER FLOW AND TREATMENT FACILITIES AT MILL 3105


MINE
10,900 m3/day
(2,880,000 gpd)
2,615 m3/day
(690,000 gpd)
7.3-hectare
(18-acre)
RESERVOIR
8,300 m3/day
(2,190,000 gpd)
7,900 m3/day
(2,090,000 gpd)
THICKENERS
MINE-WATER
TREATMENT
MILL
Pb
Cu
Zn
8,300 m3/day
(2,190,000 gpd)
DISCHARGE
TAILINGS
(35% SOLIDS)
5,510 m3/day
(1,460,000 gpd)
2,380 m3/day
(630,000 gpd)
7,900 m3/day
(2,090,000 gpd)
TAILING
LAGOON
RECYCLE
5,300 m3/day
(1,400,000 gpd)

combined retention time in the two ponds is 35 days at maximum flow. A schematic diagram of the mill-water circuit is shown in Figure VII-14. The separate treatment of mine water and surface runoff would allow this operation to achieve total recycle. Discharge data for this mine/mill complex were presented as mine discharge for mine 3101 earlier in this section.

Mill 3108 is located in Idaho and recovers sphalerite, galena, and tetrahedrite from approximately 158,725 metric tons (175,000 short tons) of ore per year.

At this facility, the coarse tailings fraction is mixed with cement and used for backfilling stopes in the mine. Mine water, including mill wastewater delivered with the sand backfill, is combined with the mill tailings stream, and flocculant is added prior to settling in the mill tailing pond (for approximately 72 hours) and discharge. Alkalinity, for precipitation of heavy metals, is currently derived from cement added to mine backfill and from reagent use in the milling process. Wastewater flow and treatment practices are illustrated in Figure VII-15, while effluent characteristics are shown in Table VII-18.

Gold Ores

The discussion that follows describes treatment and control technology in current use in the gold-ore mining and dressing industry. Aspects of treatment and control which are unique to the gold-ore category are described, in addition.

Mining Operations. Wastewater treatment at mining operations in the gold-ore mining industry consists of three options as currently practiced in the U.S.: (1) Direct discharge without treatment; (2) Incorporation of mine water into a mill processwater circuit; and (3) Impoundment and discharge. Impoundment of mine water without discharge may be currently practiced at locations in arid regions, due to evaporation.

Wastewater emanating from placer mining operations consists primarily of water used in a gravity separation process. Recovery of placer gold by physical methods involves no crushing, grinding, or chemical-reagent usage. As a result, the only waste parameters requiring treatment for removal are the suspended and/or settleable solids generated during washing (i.e., sluicing, tabbing, etc.) operations. Current best treatment practice in this segment of the industry is

Figure VII-14. SCHEMATIC DIAGRAM OF TREATMENT FACILITIES AT MILL 3101

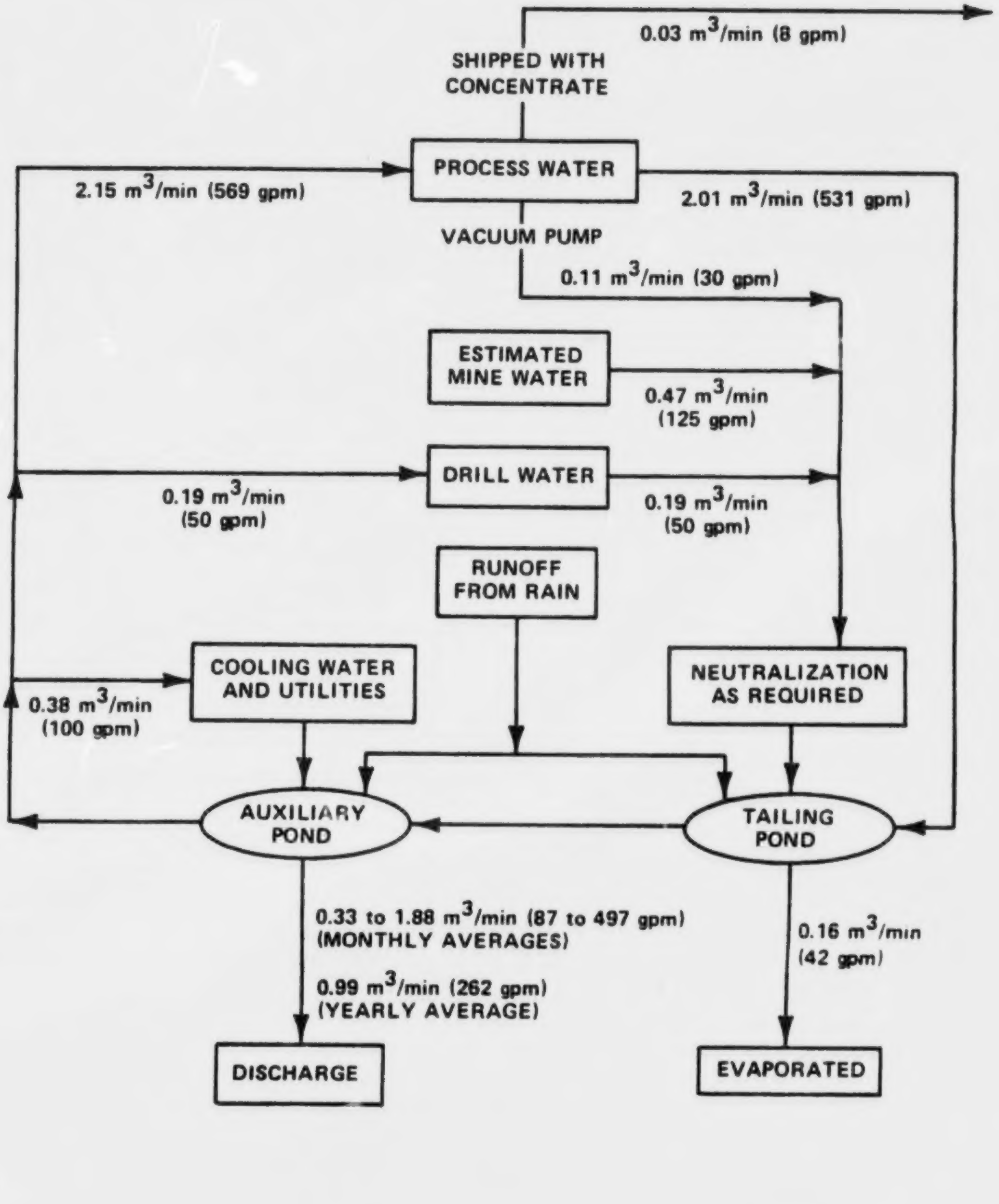

0.03 m3/min (8 gpm)
SHIPPED WITH CONCENTRATE
PROCESS WATER
2.15 m3/min (569 gpm)
2.01 m3/min (531 gpm)
VACUUM PUMP
0.11 m3/min (30 gpm)
ESTIMATED MINE WATER
0.47 m3/min (125 gpm)
DRILL WATER
0.19 m3/min (50 gpm)
0.19 m3/min (50 gpm)
RUNOFF FROM RAIN
COOLING WATER AND UTILITIES
0.38 m3/min (100 gpm)
NEUTRALIZATION AS REQUIRED
AUXILIARY POND
TAILING POND
0.33 to 1.88 m3/min (87 to 497 gpm) (MONTHLY AVERAGES)
0.99 m3/min (262 gpm) (YEARLY AVERAGE)
0.16 m3/min (42 gpm)
DISCHARGE
EVAPORATED

Figure VII-15. SCHEMATIC DIAGRAM OF WATER FLOW AND TREATMENT FACILITIES AT MINE/MILL 3108

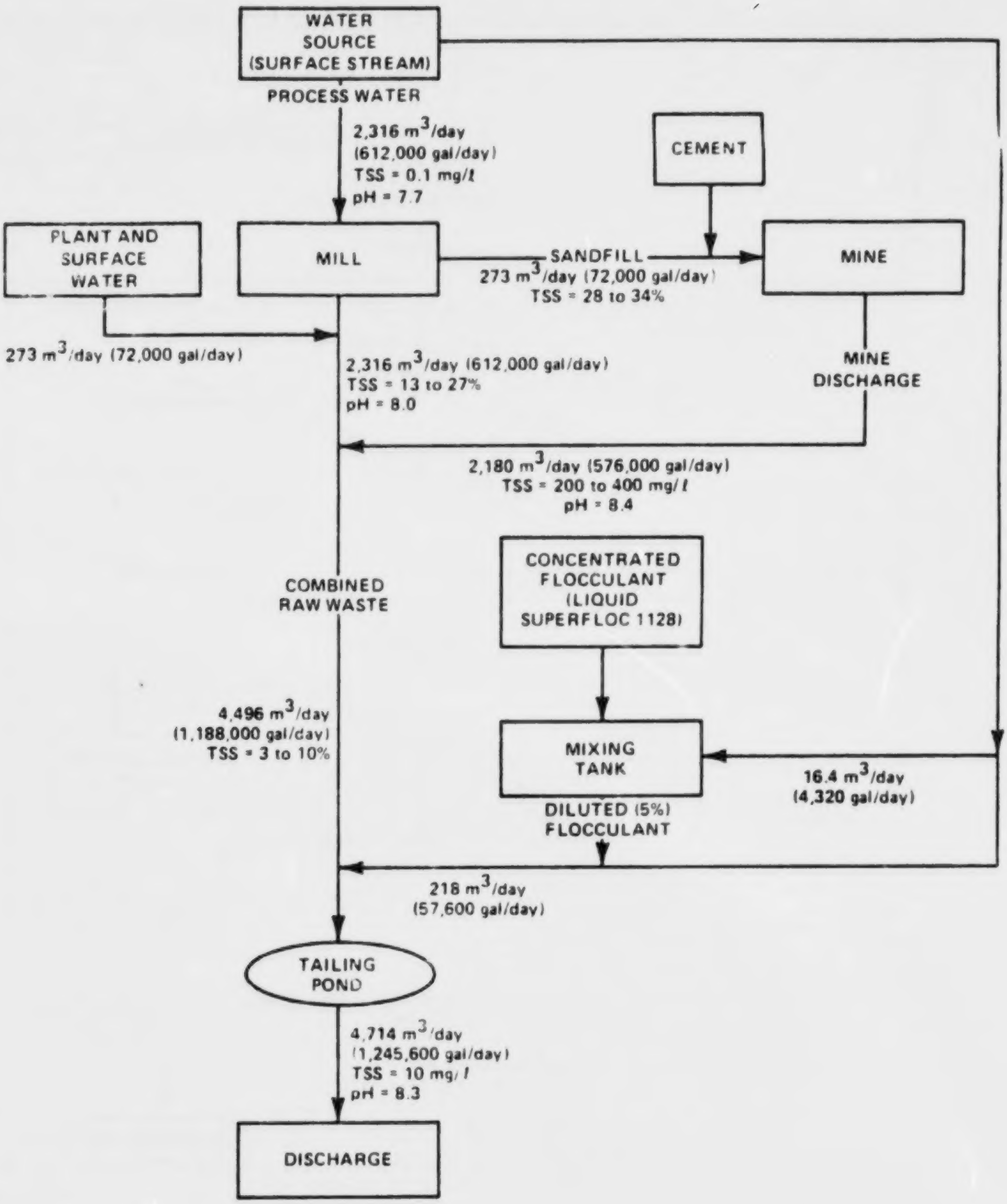

WATER SOURCE (SURFACE STREAM)
PROCESS WATER
2,316 m³/day (612,000 gal/day) TSS = 0.1 mg/l pH = 7.7
CEMENT
PLANT AND SURFACE WATER
MILL
SANDFILL
273 m³/day (72,000 gal/day) TSS = 28 to 34%
MINE
273 m³/day (72,000 gal/day)
2,316 m³/day (612,000 gal/day) TSS = 13 to 27% pH = 8.0
MINE DISCHARGE
2,180 m³/day (576,000 gal/day) TSS = 200 to 400 mg/l pH = 8.4
COMBINED RAW WASTE
CONCENTRATED FLOCCULANT (LIQUID SUPERFLOC 1128)
4,496 m³/day (1,188,000 gal/day) TSS = 3 to 10%
MIXING TANK
16.4 m³/day (4,320 gal/day)
DILUTED (5%) FLOCCULANT
218 m³/day (57,600 gal/day)
TAILING POND
4,714 m³/day (1,245,600 gal/day) TSS = 10 mg/l pH = 8.3
DISCHARGE

TABLE VII-18. CHEMICAL COMPOSITION OF MILL WASTEWATER FOR MILL 3108

PARAMETER	CONCENTRATION (mg/ℓ)		
		TREATED WASTEWATER[†]	
	RAW WASTEWATER*	MEAN	RANGE
pH	7.9**	7.5**	6.6 TO 9.1**
TSS	125,000	24	0.8 TO 134
Cd	1.5	0.002	0.0008 TO 0.004
Cu	9.0	0.01	0.003 TO 0.022
Hg	–	0.00036	0.00008 TO 0.0011
Pb	560	0.242	0.095 TO 0.48
Zn	182	0.118	0.051 TO 0.210

*For 24-hour composite verification sample.

[†] From company monitoring data for period November 1974 through March 1976. Mean values are averages of monthly mean data; range is lowest monthly average and highest single-day concentrations observed.

**Value in pH units.

use of a dredge pond or a sedimentation pond for solids settling or, in some instances, discharge of wastewater across old tailings to achieve a filtering effect. The waste-load reductions achieved by selected placer mining operations employing this technology are presented in Table VII-19.

Techniques used for the control of suspended and settleable solids discharged from placer mining operations, regardless of size, are not being employed on a major scale at present. The termination of mining operations, even with treatment facilities, does not eliminate water-quality degradation, however, because most operations which use impoundment usually construct the settling or tailing pond adjacent to the stream being worked. With erosion taking place continuously, these facilities are seldom permanent.

Mining operations exploiting lode ores which discharge mine water from open-pit or underground operations typically either discharge directly to a receiving stream, provide process water for a mill circuit, or discharge wastewater to a mill tailing pond. Examples are underground mines 4102 and 4103 (which discharge directly to streams) and mine 4105 (the discharge of which is used as makeup water in a mill). Discharge from underground mine 4104 is impounded; however, seepage from the impoundment pond travels underground to a nearby stream. At present, no discharge of water from open-pit mine 4101 is necessary, since no seepage into the pit occurs. The small amount of precipitation and runoff entering the pit is simply allowed to evaporate.

Milling Operations. In-plant control techniques and processes used by the gold milling industry are processes which were designed essentially for reagent conservation. These processes are the reagent circuits indicated in the process diagrams of Figures III-9 and III-10.

In the cyanidation process used at mills 4101, 4104, and 4105, gold is precipitated from pregnant cyanide-leach solutions with zinc dust. The precipitate is collected in a filter press, and the weak, gold-barren cyanide solution which remains is recycled back to the leaching circuit. This solution may be used as a final weak leach, or the solution may be returned to its initial concentration with the addition of fresh cyanide and used as a strong leach. In these processes, recycling of cyanide reagent effects an estimated 33- to 63-percent saving of this reagent. Loss of cyanide from the mill circuit is primarily through retention in the mill tailings. Recycling of cyanide reduces the

TABLE VII-19. CHARACTERISTICS OF RAW AND TREATED WASTEWATER AT SELECTED PLACER MINING OPERATIONS

PARAMETER	CONCENTRATION (mg/ℓ)							
	MINE 4110*		MINE 4112		MINE 4113†		MINE 4114	
	BEFORE SETTLING	AFTER SETTLING	BEFORE SETTLING	AFTER SETTLING	BEFORE SETTLING	AFTER SETTLING	BEFORE SETTLING	AFTER SETTLING
pH	7.2**	7.2**	6.9**	7.9**	7.3**	–	7.2**	7.4**
D.O.	5.2	6.4	–	–	< 1	–	8.0	4.0
TURBIDITY (NTU)	3,200	600	900	0.45	31,200	0	32,800	1.0
TSS	47,100	1,420	9,670	0.3	535,000	0	94,600	22
SETTLEABLE SOLIDS	60††	1.5††	20††	< 0.1††	104††	0††	186††	< 0.1††
SIZE OF OPERATION IN AMOUNT OF MATERIAL MOVED/DAY	214 m^3/day (280 yd^3/day)		382 m^3/day (500 yd^3/day)		NOT AVAILABLE		765 to 1529 m^3/day (1,000 to 2,000 yd^3/day)	

*The two settling ponds were full. Treatment was essentially filtration across old tailings.

†No discharge; wastewater impounded in three ponds.

**Value in pH units.

††Value in mℓ/ℓ.

quantity of cyanide used and also reduces the amount of reagent present in effluent from discharging mills.

In a similar manner, mercury is typically recycled in amalgamation processes. Currently, amalgamation is practiced at only one milling operation (mill 4102). This mill uses a barrel amalgamation process to recover gold. At this mill, the gold is separated from the amalgam in a high-pressure press, and the mercury is returned to the amalgamator for reuse. Some mercury is lost from this circuit--primarily, through retention in the mill tailings.

Ultimate recovery or removal of mercury from the waste stream of a mill presents an extremely difficult task. To do so requires removing a small concentration of mercury, usually from a large volume of water. Advanced waste treatment methods, such as ion exchange, might achieve as much as 99 percent removal, but the expense for treating large volumes of water would be high. Primarily as a result of this, and in light of recent stringent regulation of mercury in effluents, the gold milling industry has been taking advantage of the process flexibility available to it and has, for the most part, replaced amalgamation with cyanidation processes for gold recovery. This process flexibility is the best control currently being practiced by the industry for minimizing or eliminating mercury waste loading.

The primary wastes emanating from a gold mill are the slurried ore solids. For this reason, mill effluents are typically treated in tailing ponds, which are designed primarily to provide for the settling and collection of the suspended solids in the mill tailings. In most cases, these operations discharge from tailing ponds, and the usual practice is to decant the water from the top of the pond at a point where maximum clarification has been attained. In some facilities, two or more ponds are connected in series, and wastewater is decanted from one to another before final discharge.

Although the structure, design, and methods of ponding may vary somewhat in accordance with local topography and volume of wastewater, the desired goal is the same--to achieve maximum settling and retention of solids.

To illustrate the effectiveness of settling ponds as treatment systems in the gold-ore milling industry, the discussion which follows outlines an operation which recovers gold and other metals and treats wastewater by use of a tailing pond.

Mill 4102 is located in Colorado. This mill beneficiates ore containing sulfides of lead, zinc, and copper, in addition to native gold and silver. During 1973, 163,260 metric tons (180,000 short tons) of ore were milled to produce lead/copper and zinc concentrates by flotation and gold by amalgamation.

Makeup water for the mill circuit is drawn from a nearby creek. This water is introduced into the grinding circuit for transportation and flotation of the ore. Prior to entering the flotation circuit, the ground ore is jigged to produce a gravity concentrate. This concentrate contains most of the gold, which is recovered by amalgamation. After amalgamation, the jig concentrate is fed into the flotation circuit, because some lead is contained in the material.

Mill tailings are discharged to a tailing pond at a rate of 2,290 cubic meters (600,000 gallons) per day. Decant from this pond flows to a smaller polishing pond prior to final discharge to a stream. The tailing pond and the polishing pond have a total area of 18.2 hectares (45 acres).

Table VII-20 presents the chemical composition of mill water and raw and treated waste load for mill 4102, which practices amalgamation for gold and froth flotation for sulfide minerals. These data indicate that removal of selected metals is achieved to a degree; however, the treatment is most efficient in the removal of suspended solids.

Mill 4101 is located in Nevada. This mill recovers gold occurring as native gold in a siltstone host rock which is mined from an open pit. Schuetteite ($HgSO_4 \cdot 2HgO$) also occurs in the ore body, and mercury is recovered as a byproduct during furnacing of the gold concentrate. Ore milled during 1973 totaled 750,089 metric tons (827,000 short tons). This figure normally is 770,950 metric tons (850,000 short tons) but was lower than usual due to a 20-day labor strike.

This mill employs complete recycle of the tailing-pond decant. However, due to consumptive losses, some makeup water is required, and this water is pumped to the mill from a well. Water is introduced into the grinding circuit for transportation and processing of the ore by the agitation/cyanidation-leach method.

TABLE VII-20. WASTE COMPOSITIONS AND RAW AND TREATED WASTE LOADS ACHIEVED AT MILL 4102 BY TAILING-POND TREATMENT

PARAMETER	MILL WASTEWATER			TAILING-POND EFFLUENT		
	CONCENTRATION (mg/ℓ)	RAW WASTE LOAD per unit ore milled		CONCENTRATION (mg/ℓ)	TREATED WASTE LOAD	
		kg/1000 metric tons	lb/1000 short tons		kg/1000 metric tons	lb/1000 short tons
pH	9.1*†	–	–	10.0*	–	–
TSS	495,000	2,871,000	5,742,000	4	20	40
COD	11.42	66	132	22.85	130	260
Oil and Grease	1	5.8	11.6	1	6	12
Cd	< 0.02	< 0.12	< 0.24	< 0.02	< 0.1	< 0.2
Cr	< 0.02	< 0.12	< 0.24	0.05	0.3	0.6
Cu	0.03	0.17	0.34	1.2	7	14
Total Fe	1.0	6	12	1.5	9	19
Pb	< 0.1	< 0.6	< 1.2	< 0.1	< 0.6	< 1.2
Total Mn	8.25	49	98	6.37	40	80
Hg	0.0014	0.008	0.016	0.0011	0.006	0.012
Zn	1.3	7.5	15.0	0.05	0.3	0.6

*Value in pH units

††Industry data monthly average over period November 1973 through November 1974

Mill tailings are discharged at a rate of 2,305 cubic meters (603,840 gallons) per day to a 37-hectare (92-acre) tailing pond. Approximately 1,227 cubic meters (321,500 gallons) per day of tailing-pond decant are pumped back to the mill from a reclaim sump. No discharge from this operation results. Potential slime problems in the mill circuit are controlled through adjustment of the pH to 11.7 and by use of Separan flocculant in the circuit.

Table VII-21 gives the results of chemical analysis of mill effluent and tailing-pond decant water after treatment. No waste loadings are given, since no discharge results. Samples were obtained from this facility to determine the effectiveness of treatment, even though the mill has no discharge. Note, however, that this mill has an alkaline-chlorination unit available for use in cyanide destruction should emergency conditions require a discharge.

Data from both mills indicate that dissolved heavy metals are removed to some degree in the tailing pond, but more effective technology is required for removal of these waste constituents. Although such technology is not currently used in the gold mining and dressing industry, it is currently available and in general use in other segments of the mining and dressing industry. This technology also has special application to mine discharges, as they usually contain relatively high dissolved-metal loads. This technology will also be applicable to those situations where sufficient reduction of metals and cyanide in tailing-pond effluents is not being achieved.

Conventional treatment available for dissolved heavy metals generally involves:

(1) Coagulation and sedimentation employing alum, iron salts, polyelectrolytes, and others.

(2) Precipitation with lime, soda ash, or sulfides.

These treatment technologies have been previously discussed in this section. Treatment by these methods is not normally practiced in this industry category. However, where metal mining wastes are treated, the most common means used is to discharge to a tailing pond, in which an alkaline pH is maintained by lime or other reagents. Heavy-metal ions are precipitated at elevated pH; these ions are then settled out, together with suspended solids, and maintained in tailing ponds.

TABLE VII-21. CHEMICAL COMPOSITIONS OF MILL WASTEWATER AND TAILING-POND DECANT WATER AT MILL 4101 (NO RESULTANT DISCHARGE)

PARAMETER	CONCENTRATION (mg/ℓ)	
	MILL WASTEWATER	TAILING-POND DECANT
pH	12.26*	11.29*
TSS	545,000	12
Turbidity (JTU)	6.70	1.0
TDS	4,536	4,194
COD	43	43
Oil and Grease	< 1	< 1
Cyanide	5.06	5.50
As	0.05	0.04
Cd	0.10	0.02
Cr	0.06	0.03
Cu	0.17	0.13
Total Fe	< 0.5	< 0.5
Pb	< 0.1	< 0.1
Total Mn	0.02	0.90
Hg	–	0.152
Zn	3.1	2.5

*Value in pH units.

Mercury presents a special problem for control, due to its potential for conversion in the environment to its highly toxic methyl-mercury form. The amalgamation process still finds some use in the gold milling industry, and, in addition, this metal sometimes occurs with gold in nature. Although mercury will precipitate as the hydroxide, the sulfide is much more insoluble. It is expected that, where dissolved mercury occurs in mine or mill wastes, it will be treated for removal by sulfide addition. This reaction requires alkaline conditions to prevent the loss of sulfide ion from solution as H_2S. Theoretical considerations of solubility product and dissociation equilibria suggest that, at a pH of 8 to 9, mercury ion will be precipitated from solution to a concentration of less than 10 exp(-41) g/l. In practice, it is not likely that this level can be achieved. However, by optimizing conditions for sulfide precipitation, mercury should be removed to a concentration of less than 0.1 microgram/liter (0.1 ppb).

The conditions under which lime precipitation of heavy metals is achieved must take into consideration auxiliary factors. As indicated, the most important of these factors is pH. The minimum solubility of each metal hydroxide occurs at a specific pH; therefore, optimum precipitation of particular metals dictates regulation and control of pH. When more than one metal is to be precipitated, the pH must necessarily be compromised to obtain the maximum coprecipitation achievable for the given metals.

Another factor which must be considered is the oxidation state(s) of the metal or metals to be treated. For example, As(+5) is much more amenable to chemical treatment than is As(+3). In addition, cyano-metallic or organo-metallic complexes are generally much more difficult to remove by chemical treatment than are free metal ions. Where these factors impede chemical treatment, prior oxidation of the waste stream can be employed to destroy the metal complexes and oxidize metal ions to a form more amenable to chemical treatment. This oxidation may be achieved by aeration of the waste stream or by the addition of chlorine or ozone.

To achieve high clarification and removal of solids and chemically treated metals, it is essential to provide good sedimentation conditions in the tailing pond. Typically, this is done in the industry by designing tailing ponds to provide adequate retention time for the settling of solids and metal precipitates. Specification of a recommended retention time for traditional tailing-pond design is problematical, because the influence of pond geometry, inlet/outlet details, and other factors that ensure even distribution and an absence of short-circuiting are of greater importance than the theoretical retention provided. A design retention time of 30 days, based on the average flow to be treated, is often specified and is appropriate if short-circuiting due to turbulence or stratification does not occur. The use of a two-cell pond is recommended to increase control and reliability of the sedimentation process.

In some cases, suspended solids or metal precipitates may retain surface charges or colloidal properties and resist settling. These solids and colloids can be treated for removal by the addition of coagulating agents, which either flocculate or act to neutralize or insulate surface charges and cause the suspended solids and colloids to coagulate and settle. These agents may be such flocculants as alum ($Al_2(SO_4)_3$) or iron salts, or such coagulants as clays, silica, or polyelectrolytes.

Cyanide destruction has been previously discussed in this section. The technology for oxidation and destruction of cyanide is well-known and currently available. Where discharges of cyanide have the potential to enter the environment, complete destruction prior to discharge is recommended.

Technology For Achieving No Discharge of Pollutants. Elimination of point discharges is currently being achieved in the industry by two slightly different technologies: impoundment and recycle. Where impoundment is used, the mill tailings are simply discharged to a pond and retained there. Recycling exists where tailing-pond water is decanted and returned to the mill for reuse. A mill or mine/mill complex is potentially capable of employing either of these technologies, whereas a mine alone may only be able to make use of impoundment.

The feasibility of impoundment is dependent on the overall water balance of the location of the mine/mill's mine or mill. In arid regions, the impoundment of tailings is a feasible alternative to discharging and is, in fact, being practiced.

Where recycle systems are employed, the design must also take water balance into consideration. In those areas where precipitation exceeds evaporation during all or part of the year, some system to divert runoff away from the tailing pond is required to keep excess water in the pond to a minimum. Also, where heavy rainfalls periodically occur, tailing ponds must be designed to hold the excess water accumulated during these periods. A mine/mill complex may find it necessary to segregate the mine and mill effluents to further relieve the recycle system of excess water. In such cases, it is expected that the mine effluents will be treated by the chemical methods discussed previously and then discharged.

To some extent, a mill may depend on inherent loss of water from the system to maintain a balanced recycle system. These losses include any or all of the following:

(1) Consumptive losses in the milling process (i.e., retention of mositure in the concentrate, etc.);

(2) Retention of moisture by the tailing solids in the tailing pond;

(3) Evaporation;

(4) Seepage and percolation of water from the tailing pond.

The extent of these losses is dependent on a number of factors, namely:

(1) Milling process employed;

(2) Evaporation rate (function of climate and topography);

(3) Type of material used to construct the tailing pond;

(4) Characteristics of tailing solids;

(5) Characteristics of soil underlying the tailing pond;

(6) Use of liners, diversion ditches, and other methods.

Given the present state of technology available and the demonstrated status of recycle within the gold milling industry, the maintenance of a balanced recycle system is technologically feasible.

The feasibility of a recycle system must also consider the effects of the reclaim water upon the mill circuit. For example, it has been indicated previously that reclaiming cyanidationprocess water could result in a loss of gold should this water be introduced at the ore-grinding stage.

In the Province of Ontario, it has been found that the level of cyanide in the tailing-pond decant from active mine/mill operations approximates 0.02 to 0.5 percent of total cyanide mill additions (Reference 64). However, data indicate that the concentration of cyanide in tailing-pond decant may build up if the decant is being reclaimed. If this occurs, the alkaline-chlorination method can be used for cyanide destruction. Complete destruction of cyanide can be achieved by excess addition (8.5:1) of chlorine. On this basis, the recycling of cyanidation-process water is considered technologically feasible.

Recycling and zero discharge are currently being accomplished at mill 4101, which is milling gold by the cyanide/agitationleach process (Figure III-10). The overall water balance for this mill has been presented in Figure V-22. Treatment efficiency data for this mill, presented in Table VII-21, indicate a buildup of dissolved solids and cyanide in the reclaim water. However, no loss in percent recovery as a result of recycling has been reported by this mill. In addition, the recovery rate for this mill does not differ from that of cyanidation mill 4105, which does not recycle process water.

Silver Ores

The discussion which follows describes treatment and control technology currently employed in the silver-ore mining and dressing industry. Aspects of treatment and control pertaining to the silver-ore category are described.

Mining Operations. Wastewater treatment at silver mining operations primarily consists of discharge of wastewater to a mill tailing pond, or direct discharge without treatment. Mining of silver ores primarily exploits the sulfide minerals tetrahedrite ($(Cu, Fe, Zn, Ag)_{12}Sb_4S_{13}$) and argentite ($Ag_2S$) and native silver. Native silver often occurs with gold, copper, lead, and zinc minerals. Little water use is encountered in silver-ore mining, with the exception of dredging, where silver is recovered as a minor byproduct.

Separate treatment of mine water per se is not typically practiced in this industry; however, where practiced, treatment is performed in conjunction with treatment of mill wastewater in a tailing pond.

Milling Operations. As discussed in Section V, milling processes currently employed in the silver industry are froth flotation (about 99 percent of U.S. mill production), cyanidation of gold ores, and amalgamation. Cyanidation and amalgamation recovery of silver currently constitute approximately 1 percent of U.S. silver production by milling. The occurrence of silver, either with gold in a free state or as a natural alloy with gold, has also resulted in production of silver at refineries. Silver is often recovered also as a byproduct of the smelting and refining of copper, lead, and zinc concentrates.

Cyanidation for gold and silver is currently being practiced at mill 4105 (gold category), but wastewater treatment technology as currently practiced consists of a sand reclaimer pond for removal of coarse solids only. Amalgamation for gold and silver is currently limited to one known site. Wastewater treatment at this facility has been described previously for mill 4102.

Mill 4105, which recovers both gold and silver, currently practices in-plant recycling of reagents, as indicated in Section III for Gold Ores. This results in economies of both cost and reagent use, as well as prevention of the discharge of cyanide for treatment or into the environment. In-plant control practices common to silver flotation mills are based on good housekeeping measures, employed to prevent spills of flotation reagents. The feed of these reagents into a circuit is carefully controlled, because a sudden increase or decrease of some reagents could have adverse effects on recovery from the flotation circuit.

Wastes resulting from silver milling are typically treated in tailing ponds. These ponds function primarily to facilitate the settling and retention of solids. Except in the case of total impoundment, the clarified tailing-pond water is currently discharged. At mill 4401, a further reduction of waste loading is achieved by partial recycle of the tailing-pond decant water (approximately 60- to 75-percent recycle). Mill 4402 has achieved zero discharge through total recycle of tailingpond decant water. Flotation is the predominant method currently used to concentrate silver ore. Flotation circuits are commonly run under alkaline conditions. For example, soda ash, caustic soda, and hydrated lime are added to the circuit of mill 4402, and lime is added to the circuit of mill 4401. These reagents are added to the mill circuits to act as depressants and pH modifers and consequently make the tailing pond alkaline. This facilitates the removal of metals as hydroxides in the tailing pond. However, note that the reagents producing an alkaline pH in the tailing pond are added in the mill to control the process conditions there, and a high degree of control over the pH in the tailing pond is not currently practiced in the industry. To facilitate optimum precipitation of metal hydroxides in the tailing pond, a higher degree of control over the pH may be required in some cases. Highly alkaline conditions (pH range of 10 to 11) may be required to effect greater removal efficiency in treatment facilities.

The presence of antimony in wastewater has been noted, because it is closely associated with silver in some ore bodies--especially, those of the Coeur d'Alene District of Idaho. The hydroxide of antimony is not reported to exist but the sulfide of antimony is relatively insoluble; therefore, treatment for antimony removal will involve sulfide precipitation. Although Na_2S is itself toxic at high concentrations, the amount required to treat the levels of antimony found in mine and mill wastewater (approximately 2 to 3 mg/l) is small (approximately 1 mg/l) and will be consumed in the precipitation reaction. Sulfide precipitation must be carried out under alkaline conditions to prevent the removal of sulfide ion from solution as H_2S gas.

Cyanide is used as a pyrite depressant at mill 4401. This mill is also recycling its process water with no apparent adverse affects from this reagent. However, should the destruction of cyanide become necessary for process control or as a safety measure in treating accidental leaks from the treatment system, alkaline-chlorination, ozonation, or hydrogen peroxide treatment are effective treatment technologies for the destruction of cyanide. These processes have been discussed previously in this section. An example of tailing-pond treatment as practiced at mill 4401 is described below.

Mill 4401 is located in Idaho. Ore is brought to the mill from an underground mine. Valuable minerals in the ore body are primarily tetrahedrite, but chalcopyrite and galena also occur. During 1973, 182,226 metric tons (200,911 short tons) were milled to produce a copper/ silver concentrate.

Water used at the mill consists of both reclaim water and makeup water, pumped from a nearby creek. This water is introduced into the grinding circuit for the transportation and flotation of the ground ore. Mill tailings are discharged at a rate of 3,188 cubic meters (835,200 gallons) per day to the tailing-pond system. This system is composed of three tailing ponds and a clarification pond. Two of the tailing ponds are inoperative, due to extensive damage resulting from a recent flood. Prior to this flood, tailings were distributed to the three ponds, and their decant was pumped to the clarification pond. This system covers a total area of 4.5 hectares (10.9 acres). Presently, water is both discharged and recycled back to the mill from the clarification pond. Approximately 1,649 cubic meters (432,000 gallons) per day are recycled, while 1,141 cubic meters (299,000 gallons) per day are discharged, Mine water is also discharged to this pond system at a rate of 553 cubic meters (145,000 gallons) per day.

A new tailing pond is under construction and is expected to be in use soon. This pond will have an area of 6.9 hectares (17.0 acres).

Table VII-22 gives the chemical composition of raw and treated waste loads from mill 4401, which uses tailing pond treatment. Decreases in several parameters, in addition to suspended-solid removal, are noted. TOC, COD, cyanide, copper, mercury, and nickel are all reduced significantly.

Control and Treatment Technology To Achieve No Discharge. Currently, two silver mills are recycling their process water. Mill 4402 reclaims all of its tailing-pond decant, while mill 4401 presently reclaims approximately 60 percent of its tailing-pond decant. However, operation of mill 4401 with complete recycle could be achieved, and would be, were it not currently less expensive to use fresh water pumped from a nearby well, rather than recycled process water from an impoundment as makeup water.

The feasibility of recycle entails consideration of the overall water balance at a given mill and possible interferences in the mill circuit caused by the recycling of process reagents and/or buildup of dissolved solids. Water-balance considerations and recycling of cyanide reagent have been discussed previously in Section VII.

Silver ores are concentrated primarily by the froth flotation process, and it has been noted previously that recycled flotation reagents might interfere with the mill

TABLE VII-22. WASTE COMPOSITIONS AND RAW AND TREATED WASTE LOADS AT MILL 4401 (USING TAILING-POND TREATMENT AND PARTIAL RECYCLE)

PARAMETER	MILL WASTEWATER			TAILING POND EFFLUENT		
	CONCENTRATION (mg/ℓ)	RAW WASTE LOAD per unit ore milled		CONCENTRATION (mg/ℓ)	RAW WASTE LOAD per unit ore milled	
		kg/1000 metric tons	lb/1000 short tons		kg/1000 metric tons	lb/1000 short tons
pH	–	–	–	7.0*	–	–
TSS	555,000	2,497,000	4,994,000	< 2	< 3	< 6
Turbidity (JTU)	2.0	–	–	0.6	–	–
COD	59.5	268	536	19.8	32	64
TOC	22.0	100	200	17.5	28	56
Oil and Grease	7	30	60	12	19	38
Cyanide	0.05	0.23	0.46	0.025	0.04	0.08
As	< 0.07	< 0.11	< 0.22	< 0.07	< 0.11	< 0.22
Cd	< 0.02	< 0.03	< 0.06	< 0.02	< 0.03	< 0.06
Cr	< 0.1	< 0.16	< 0.32	< 0.1	< 0.16	< 0.32
Cu	0.25	1.1	2.2	0.08	0.13	0.26
Total Fe	–	–	–	0.10	0.16	0.32
Pb	< 0.1	< 0.16	< 0.32	< 0.1	< 0.16	< 0.32
Mn	–	–	–	0.39	0.62	1.24
Hg	0.0024	0.011	0.022	0.0005	0.0008	0.0016
Ni	0.14	0.63	1.26	0.06	0.1	0.2
Ag	< 0.02	< 0.03	< 0.06	< 0.02	< 0.03	< 0.06
Zn	< 0.02	< 0.03	< 0.06	0.02	0.03	0.06
Sb	1.85	8.3	16.6	1.0	1.6	3.2

*Value in pH units

circuit. However, no published data exist which would support this position. Recycling successfully being carried on at mill 4402 (total recycle--no discharge) and mill 4401 (partial recycle) demonstrates the feasibility of achieving total recycle and zero discharge. It is expected that unwanted quantities of a particular frother appearing in a recycle stream (from a tailing area, etc.) can probably be reduced or eliminated by:

(1) increasing the retention time of the frother-containing wastes to facilitate increased oxidation or biodegradation before recycle to the mill; or

(2) oxidation of the frothers through application of a degree of mechanical aeration, etc., to the waste stream; or

(3) selecting another frother with superior breakdown properties for use in the mill.

A further degree of control of the recycle system can be gained by use of a two-cell pond. In this system, clarified water from the primary pond would be decanted to the second pond, which would be used as a surge basin for the reclaim water. This system would lend itself to increased control over the slime content of reclaim water. This is desirable, since these slimes have been thought to inhibit differentialflotation processes in some mills. In addition, the second pond would provide a site for the implementation of mechanical aeration, should this treatment become necessary.

Segregation of Waste Streams. At certain mine/mill complexes, for the mill to achieve a balanced recycle system, it may be necessary to segregate the mine and mill waste streams. In such cases, it is expected that, prior to discharge, the mine effluents would be chemically treated for the removal of metals and suspended solids in settling ponds. As previously discussed, this treatment would normally involve precipitation of metals using lime and/or sulfides.

The discussion which follows describes a silver milling operation currently operating with recycle and zero discharge.

Mill 4402 is located in Colorado. Ore is brought to the mill from an underground mine. Valuable minerals in the ore body include sulfide of silver--primarily, argentite, galena, and free or native silver. During 1973, 75,005 metric tons (82,696 short tons) of this ore were milled to produce a lead/silver concentrate.

Process water is recycled at this mill. However, makeup water is required, and this water is pumped from a well. Water is introduced into the grinding circuit to facilitate transportation and flotation of the ground ore. Mill tailings are sent through two stages of cyclones to remove sands, which are used for backfilling stopes in the mine. Cyclone overflow is discharged to a 1.6-hectare (4-acre) tailing pond at a rate of 1,511 cubic meters (396,000 gallons) per day. Clarified pond water is recycled back to the mill at a rate of 962 cubic meters (252,000 gallons) per day.

A new tailing pond is being built at this mill. This pond will have an area of 6 hectares (15 acres).

Table VII-23 demonstrates the treatment efficiency achieved in the mill tailing pond and compares mill raw-wastewater input to tailing-pond decant water recycled to the mill. No waste loads are presented, because no discharge results.

Bauxite Ore

As discussed in Section IV, Industry Categorization, two bauxite mines currently operating in the U.S. extract bauxite ores from open-pit and underground mines. The characteristics of pollutants encountered in wastewaters from these operations are discussed in Section V. The current treatment technology and industry practice for treatment of bauxite-mine drainage are described below.

Lime neutralization is the only treatment method presently being employed by the two domestic bauxite producers to treat mine water. Both acidic and alkaline waters are treated by this technique, but, due to the relatively small amount of alkaline water that is treated daily (83 cubic meters, or 22,000 gallons, per day), only acid mine-water neutralization is discussed in detail here.

Generally, mine water and surface drainage destined for treatment undergo settling in a number of natural depressions, sumps, and settling ponds before reaching the lime-neutralization facility; thus, suspended-solids loadings are reduced.

TABLE VII-23. CHEMICAL COMPOSITIONS OF MILL RAW WASTEWATER AND TAILING-POND DECANT WATER AT MILL 4402

PARAMETER	CONCENTRATION (mg/ℓ)	
	MILL RAW WASTEWATER	TAILING-POND DECANT
TSS	90,000	2
Turbidity (JTU)	1.05	0.575
COD	22.70	22.70
TOC	29.0	17.5
Oil and Grease	2	2
Cyanide	< 0.01	< 0.01
As	0.07	< 0.07
Cd	< 0.02	< 0.02
Cr	< 0.1	< 0.1
Cu	0.22	< 0.02
Total Fe	1.80	1.59
Pb	0.56	0.10
Total Mn	1.75	1.80
Hg	0.149	0.002
Ni	0.10	0.11
Ag	< 0.02	< 0.02
Zn	0.37	2.3
Sb	< 0.2	< 0.2

The addition of lime to raw mine drainage to reach elevated pH causes precipitation of heavy metals as insoluble or slightly soluble hydroxides. Formation of specific metal hydroxides is controlled by pH, and removal of the suspended hydroxides is accomplished by settling. The discussion of this treatment technique is presented in the early portion of Section VII under Chemical Precipitation.

Two variations of lime storage at bauxite-minewater-treatment facilities are employed, and both systems achieve slightly different efficiencies of pollutant removal. The pH and pH control of the limed solution are the dominant factors in determining concentration levels attained in settling ponds.

Figure VII-16 is a schematic flowsheet of the lime-neutralization facility at open-pit mine 5102. Both mine drainage treatment systems investigated during this study are of this type and are discussed by plant code below.

Mine 5101. Open-pit mine complex 5101 is located in Arkansas and produces about 2,594 metric tons (2,860 short tons) of high-silica bauxite daily. There are several pits associated with the water-treatment facility, and acid waters collected from the pits, spoils-storage areas, and disturbed areas are directed to the treatment plant.

Mine 5101 treats the major portion of its open-pit mine drainage through a treatment plant similar to that shown in Figure VII-16. Other open-pit drainages which require intermittent pumping for discharge will be treated by a mobile lime-treatment plant in the near future. At Mine 5101, about 0.45 kg (approximately 1 pound) of slurried lime is used to neutralize 3.79 cubic meters (1000 gallons) of acid mine water. This facility has a controlling pH probe, located in the overflow from the detention tank, which activates the automatic plant and pump cutoffs at a high point of pH 9.0 and a low point of pH 6.0. The operating pH generally ranges from 7.5 to 8.0, and the pH of the effluent discharge ranges from 6.3 to 7.3.

Table VII-24 lists analytical data for raw mine water (silt-pond overflow) and treated effluent (as the discharge leaves the overflow weir at the sludge pond).

Mine 5102. Open-pit mine 5102 is also located in Arkansas and mines a high-silica-content bauxite deposit. Contaminated surface drainage from outlying areas and groundwater accumulation in the holding pond produce about

Figure VII-16. LIME-NEUTRALIZATION PLANT FOR OPEN-PIT MINE 5102

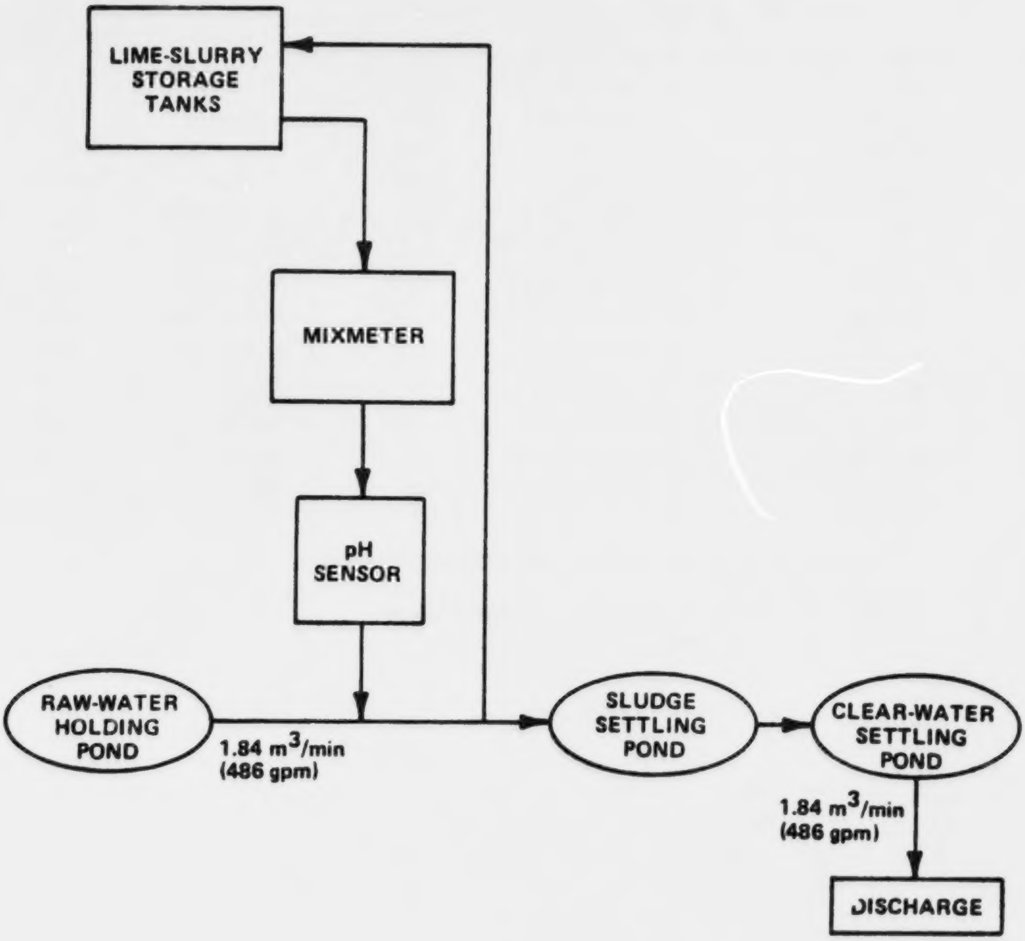

LIME-SLURRY STORAGE TANKS
MIXMETER
pH SENSOR
RAW-WATER HOLDING POND
1.84 m3/min (486 gpm)
SLUDGE SETTLING POND
CLEAR-WATER SETTLING POND
1.84 m3/min (486 gpm)
DISCHARGE

TABLE VII-24. CHEMICAL COMPOSITION OF RAW AND TREATED MINE WATERS AT MINE 5101

PARAMETER	CONCENTRATION (mg/ℓ)			
	RAW MINE DRAINAGE		TREATED EFFLUENT	
	RANGE	AVERAGE*	RANGE	AVERAGE*
pH	2.8 to 4.6†,††	3.3†,††	6.0 to 6.8†	6.4†
Acidity	250 to 397	324	0 to 1.0	0.5
Alkalinity	0	0	6 to 13.0	10
Conductivity	1000 **	1000 **	1000 **	1000 **
TDS	560 to 617	589	807 to 838	823
TSS	2 to 42††	15††	1.2 to 4.0	3
Total Fe	7.2 to 129.1††	50.9††	0.14 to 0.2	0.2
Total Mn	3.2 to 9.75††	5.5††	2.25 to 3.37	2.8
Al	2.76 to 52.3††	25.0††	0.33 to 0.8	0.6
Ni	0.3 to 0.31	0.3	0.18 to 0.19	0.2
Zn	0.82 to 1.19	1.01	0.07 to 0.09	0.08
Fluoride	0.048 to 0.29	0.17	0.03 to 0.67	0.35
Sulfate	490 to 500	495	500 to 581	541

*Values based on two grab samples unless otherwise specified
†Value in pH units
**Value in micromhos/cm and based on one grab sample
††Values based on six grab samples

14,140 cubic meters (4,000,000 gallons) of raw drainage daily. Surface drainage collects from an area of approximately 662 hectares (1,635 acres) of disturbed and undisturbed land.

An experimental lime-neutralization plant has been operated at mine 5102 and processes approximately 2,650 cubic meters (700,000 gallons) per day of acid mine drainage.

This mining operation presently treats less than 10 percent of its total raw mine drainage, but full-scale operation of a treatment plant having a capacity of 11,355 cubic meters (3,000,000 gallons) per day is expected in mid-1975. The new plant will operate similarly to the present plant, but an enlarged system of settling lagoons and sludge drying beds should provide adequate treatment efficiency.

The treatment used at mine 5102 involves slurried storage of lime in large agitator tanks for eventual mixing with mine water in the confines of a pipeline. About 0.83 kg (1.82 lb) of hydrated lime is used to neutralize 3.79 cubic meters (1000 gallons) of raw mine water. This lime rate maintains the influent to the sludge pond at a pH of 9.0 to 11.0, and effluent from the clear-water settling pond varies from a pH of 6.0 to 8.0.

Table VII-25 lists the chemical composition of both raw mine water (influent to the treatment plant) and the treated effluent (discharge from clear-water settling pond).

Ferroalloy Ores

The ferroalloy-ore mining and dressing category includes, for purposes of treatment here, operations mining and beneficiating ores of cobalt, chromium, columbium and tantalum, manganese, molybdenum, nickel, tungsten, and vanadium (one operation extracting non-radioactive vanadium). Vanadium obtained from milling of uranium, vanadium, and radium ores under NRC licensing is covered as part of the uranium-ore category. Since the subcategorization of this category is not based upon end product recovered, but rather upon the process used, representative mines and mills are used to illustrate wastewater treatment and control as practiced in ferroalloy-ore subcategories.

Currently, there are no operations mining or beneficiating ores of chromium, cobalt, columbium , and tantalum. A manganiferous ore is currently being mined at one location in the U.S., but no wastewater results, and no milling

TABLE VII-25. CHEMICAL COMPOSITIONS OF RAW AND TREATED MINE WATERS AT MINE 5102

PARAMETER	CONCENTRATION (mg/l)	
	RAW MINE DRAINAGE	TREATED EFFLUENT
pH*	2.9[†]	7.2[†]
Acidity*	240	0
Alkalinity	0	30
Conductivity *	2,212**	897**
TDS	468	630
TSS*	45	6.6
Total Fe*	49.0	0.29
Total Mn	1.56	< 0.02
Al*	14.8	0.12
Ni	0.05	< 0.02
Zn	0.24	< 0.02
Sr	0.1	–
Fluoride	0.59	0.56
Sulfate*	432	343

*Values based on industry samples and represent the average of eight or more grab samples taken in 1974.

[†] Value in pH units

**Value in micromhos/cm

activities are carried on. A second manganiferous ore mine and mill was expected to reopen in late 1975 or 1976. Consequently, treatment and control technology currently employed in the molybdenum, nickel, tungsten, and vanadium industries will be used as examples here to represent treatment used in subcategories of this category.

Mining Operations. Mining of ferroalloy ores is by both underground and open-pit methods. Mine wastewater is characterized by high and variable flow and dissolved heavy metals, and is often acidic. At open-pit mines, seasonal fluctuations in mine water may be extreme. At such operations, acidic streams from sulfides in mine waste dumps add to the waste load of the wastewater requiring treatment.

Mine water is often used as mill process water at underground mines. At open-pit operations, seasonal variability generally makes mine water an unacceptable source of process water. Treatment for suspended-solid removal is almost universally practiced in the ferroalloy-ore mining industry. Both treatment in tailing ponds with mill wastewater and use of separate treatment systems such as settling ponds and clariflocculators (variants of mechanical clarifiers in which mixing is provided for flocculant distribution) are used. Where waste streams are acidic, neutralization is generally practiced. Where open-pit mining and ore stockpiling are practiced, the potential for oxidation of metals (especially, molybdenum) increases, yielding higher levels of concentration of dissolved heavy metals and, thus, increased raw waste loads.

Examples of treatment practice are given in discussions that follow, using mines 6103, 6104, and 6107 as examples. In addition to these sites, mine water at mine 6102 is treated by neutralization and by a closed-circuit mill tailing pond from which only seasonal discharge results. Runoff from mine 6106 is treated by settling only.

Mine 6103. This mine is an underground molybdenum mine, in Colorado, which is still under development. Treatment of mine water at this site during development of the mine has included flocculant addition, spray cooling, and solids removal in a series of three settling ponds. Sanitary wastewater from the mine site is given tertiary treatment in a separate facility prior to mixing with mine water in the first settling basin. Samples of the 9,265 cubic-meter/day (2.5 mgd) mine-water flow were obtained at the point of discharge from the mine and at the overflow from the third settling pond. The results of chemical analyses of these samples of raw mine water and effluent from the treatment system are presented in Table VII-26.

Appreciable reductions of suspended solids and the heavy metals Cu, Mn, Pb, Zn, and Fe are evident. The influence of highly treated sanitary waste is, apparently, reflected in elevated COD values at the effluent from the treatment system.

Mine 6104. This mine is an underground mine, located in California, which obtains a complex ore yielding tungsten, molybdenum, and copper. The mine produces approximately 2,200 metric tons (2,425 short tons) of ore per day. Mine water pumped from the mine daily totals 47,000 cubic meters (13,000,000 gallons), of which approximately 7,000 cubic meters (1,848,000 gallons) are used, untreated, as mill process water. The remainder is treated for solids removal in a clariflocculator. Underflow from the clariflocculator is pumped to the mill tailing pond for further treatment. The bulk (approximately 90 percent) of clarified overflow is discharged, with the balance used as mill process water. Table VII-27 presents the results of chemical analyses of raw mine water and the effluent from the clariflocculator. A clariflocculator is used for treatment because of severely limited land and space availability in this area of very high relief (steep terrain). The use of ammonium nitrate-based blasting agents previously contributed to elevated nitrate and nitrogen levels in mine wastewater. This situation has been largely alleviated by a change in explosives used at the mine.

In addition to a significant reduction of suspended-solid concentrations, important reductions of Pb, Mn, and Fe have been noted.

Mine 6107. This mine is an open-pit vanadium mine, working non-radioactive ore. This operation is located in Arkansas, an area of high annual rainfall. The mine area is drained by two streams, which are considered as mine wastewater and are treated via neutralization by ammonia. Part of the wastewater is also treated by settling behind a series of rock dams.

Table VII-28 presents the results of chemical analyses of raw and treated mine wastewater at mine 6107. Neutralization and settling treatment is employed at mine discharge 005, and neutralization treatment alone is used at discharge 004. The presence of ammonia in the effluents reflects the use of ammonia for neutralization. Residual

TABLE VII-26. CHEMICAL COMPOSITIONS OF RAW MINE WASTEWATER AND TREATED EFFLUENT AT MINE 6103

PARAMETER	CONCENTRATION (mg/ℓ)	
	BEFORE TREATMENT	AFTER TREATMENT
TSS	802.9	24.3
TDS	726	564
Oil and Grease	1.0	1.0
COD	<10	67.5
As	< 0.01	< 0.01
Cd	0.16	< 0.01
Cu	0.06	< 0.02
Total Mn	5.5	1.0
Mo	< 0.1	< 0.1
Pb	0.19	0.03
V	< 0.5	< 0.5
Zn	0.47	< 0.02
Total Fe	17.0	0.17
Fluoride	4.5	3.7

TABLE VII-27. CHEMICAL COMPOSITIONS OF RAW AND TREATED MINE WATERS AT MINE 6104 (CLARIFLOCCULATOR TREATMENT)

PARAMETER	CONCENTRATION (mg/ℓ)	
	RAW WASTEWATER	TREATED WASTEWATER
pH	6.5*	7.8*
TSS	33.9	3.1
Oil and Grease	2	2.7
COD	91.3	91.3
As	< 0.07	< 0.07
Cd	< 0.01	< 0.01
Cu	< 0.02	< 0.02
Mn	0.21	0.03
Mo	< 0.1	< 0.1
Pb	0.14	0.02
V	< 0.5	< 0.5
Zn	0.05	0.03
Fe	1.51	0.12
Fluoride	0.52	0.46

*Value in pH units

TABLE VII-28. CHEMICAL COMPOSITIONS OF RAW AND TREATED WASTEWATERS AT MINE 6107

PARAMETER	CONCENTRATION (mg/ℓ)		
	DISCHARGE 005		DISCHARGE 004*
	RAW MINE WATER	TREATED EFFLUENT (NEUTRALIZATION & SETTLING)†	TREATED EFFLUENT (NEUTRALIZATION ONLY)†
Flow	15,000 m^3/day (4,300,000 gpd)	15,000 m^3/day (4,300,000 gpd)	5,000 m^3/day (1,400,000 gpd)
TSS	–	30	15
TDS	366	285	105
Oil and Grease	–	< 1	< 1
COD	31	5	5
Ammonia	–	5	10
As	< 0.07	0.020	0.01
Cd	< 0.005	0.0[illegible]	< 0.01
Cu	< 0.02	0.010	< 0.01
Mn	6.8	4.5	0.94
Mo	–	< 0.100	< 0.10
Pb	–	< 0.010	< 0.01
Zn	0.09	0.25	0.18
Fe	–	3.6	< 0.10
Fluoride	–	< 1	< 1

*Analysis of raw mine water unavailable for Discharge 004

†Company data

levels of iron and manganese in effluent from discharge 005 are noteworthy.

Milling Operations. The ferroalloy-ore milling industry has been subcategorized on the basis of process used and size, as described in Section IV. No exemplary operations were visited which belong to the mill subcategory representing operations processing less than 5,000 metric tons (5,500 short tons) per year. Operations representative of the remaining milling subcategories provide examples of the processes and all treatment options applicable to small operations as well. Treatment technology currently practiced is relatively uniform throughout the ferroalloy milling industry, although some examples of treatment for waste constituents peculiar to particular subcategories have been observed.

Commonly practiced treatment includes settling, neutralization, and recycle of process water. In addition, sites visited were observed to practice lime precipitation, distillation, and air stripping.

Mill 6101. This operation is a flotation mill recovering molybdenite concentrate on a large scale (approximately 14,000 metric tons, or 15,400 short tons, ore milled, per day). Mill 6101 is located in a mountainous area of New Mexico. Approximately 22,000 cubic meters (6,000,000 gallons) of water are used in froth-flotation processing each day. No mine water is produced, with process water being drawn from wells and a nearby river. Ore processing consists of crushing, grinding, and froth flotation. (See Section V.)

Treatment at mill 6101 utilizes tailing ponds and an additional settling pond for removal of residual suspended solids. Flocculants are added to the tailing stream, if required for settling prior to discharge. Limited amounts of water are reclaimed in thickeners at the mill site. Because the mill circuit is mildly alkaline, lime is not required to maintain neutral pH in the effluent stream.

Because the terrain near the mine and mill site did not allow development of a sound tailing-disposal area, water-treatment facilities are located at a significant distance (16 km, or 10 miles) from the mill. Tailings are delivered to the tailing ponds as a slurry, pumped through three 16-kilometer long (10-mile-long) steel pipelines, two of which are 25 cm (10 in.) in diameter, and one of which is 30.5 cm (12 in.) in diameter. Because of abrasive wear on the pipe, it is necessary to rotate and replace piping frequently. The use of end-of-line monitors in the mill control room, a change to more abrasion resistant neoprene-lined pipe, and a large tailing-disposal maintenance staff have essentially eliminated problems with recurrent spills of tailings from pipe breaks, which were experienced in the past.

Three impoundments are used at mill 6101: two tailing ponds totaling approximately 121 hectares (300 acres) in area, and a secondary settling pond with a 1.6-hectare (4-acre) surface area. The older of the two tailing ponds is nearly full and partly revegetated. The second pond contains a water pool of approximately 160 hectares (40 acres). Seepage through the second dam is limited by use of an asphalt liner. Discharge from the secondary settling pond flows through a small surface channel to the final discharge point.

In addition to the tailing and settling ponds, construction at the tailing-disposal site includes a diversion ditch and a flood-control dam to regulate drainage from a mountain, northeast of the tailing ponds. These diversion structures are sealed to protect the tailings area from the 100-year-frequency storm. Water recycle from the tailing basin is rendered extremely difficult at this plant by the large separation between the mill and tailing area, although it is technically compatible with the recovery practice.

Table VII-29 is a compilation of company chemical data for intake and treated discharge waters. Table VII-30 presents data for effluent treated using a tailing pond with secondary settling. Raw-waste characteristics for mill 6101 were presented in Section V. The effectiveness of this treatment scheme for suspended-solid removal is evident. The alkalinity of the mill wastewater results in the effective removal of most heavy metals in the tailing basins and settling pond. Significant reductions of Cd, Cu, Fe, Mn, Pb, and Zn were noted in this treatment scheme. Only total dissolved solids are discharged at a level in excess of 0.1 kg/metric ton (0.2 lb/short ton) of ore milled.

Mill 6102. At this mill, molybdenite concentrates are recovered by flotation. Byproduct concentrates of tin, tungsten, monazite, and pyrite are recovered in a complex system involving gravity separation, froth flotation, and magnetic separation. Monazite and pyrite concentrates are currently delivered to the tailing impoundment for disposal; they are not shipped. Ore processed is 39,000 metric tons

TABLE VII-29. ANALYSES OF INTAKE AND DISCHARGE WATERS FROM MILL 6101 (COMPANY DATA)

PARAMETER	AVERAGE CONCENTRATION (mg/ℓ)	
	INTAKE	DISCHARGE
Alkalinity	40	30
BOD (5-day)	< 30	< 30
COD	< 50	< 50
TDS	260	600
TSS	55	100
Hardness	155	800
Ammonia (As N)	0.6	1.0
Nitrate	0.1	0.1
Phosphorus	< 0.01	0.04
Al	0.24	0.2
Sb	< 0.1	< 0.1
As	–	–
Ba	< 0.001	< 0.001
Be	< 0.002	< 0.002
B	< 0.1	< 0.1
Cd	< 0.002	< 0.002
Ca	103	277
Cn	< 0.01	< 0.01
Co	< 0.005	< 0.005
Cu	0.02	0.02

PARAMETER	AVERAGE CONCENTRATION (mg/ℓ)	
	INTAKE	DISCHARGE
Fe	0.4	0.16
Pb	< 0.005	< 0.005
Mg	10	30
Mn	0.9	0.9
Ag	< 0.0001	< 0.0001
Mo	0.01	2
Ni	0.02	0.017
K	1	31
Se	< 0.005	< 0.005
Ag	< 0.001	< 0.001
Na	3	50
Sn	< 0.01	< 0.01
Ti	< 0.08	< 0.08
Zn	0.05	< 0.06
Sulfate	100	1000
Chloride	2	2
Fluoride	0.2	1.5
Cyanide	–	–
Thiocyanate	–	0.6

TABLE VII-30. CHEMICAL COMPOSITION OF WASTEWATER AND WASTE LOADING FOR MILL 6101

PARAMETER	CONCENTRATION (mg/ℓ)	TOTAL WASTE		WASTE LOAD per unit ore milled	
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons
TSS	4.3	73	160	5.2	10
TDS	2,272	39,000	86,000	2,800	5,600
Oil and Grease	3	51	112	3.6	7.2
COD	19.8	340	750	24	48
Total Cyanide	0.03	0.51	1.1	0.036	0.072
As	0.02	0.34	0.75	0.024	0.048
Cd	< 0.01	< 0.2	< 0.4	< 0.01	< 0.03
Cu	< 0.02	< 0.3	< 0.7	< 0.02	< 0.04
Mn	1.3	22	48	1.6	3.2
Mo	4.0	68	150	4.9	9.8
Pb	0.13	2.2	4.8	0.16	0.32
Zn	0.02	0.34	0.75	0.024	0.048
Fe	0.10	1.7	3.7	0.12	0.24
Fluoride	3.4	58	130	4.1	8.2

(43,000 short tons) per day. This mill is located in Colorado in a mountainous area.

This operation uses water on a complete-recycle basis for ten months of the year. During this period, due to consumptive losses in the mill, seepage losses, and evaporation from tailing and water-storage ponds, the net water balance for the system is negative. During the remaining two months (usually May and June), heavy influx of water to the mill tailing ponds from melting snow accumulations has necessitated discharge of water from the system. The amount and duration of this discharge have varied widely from year to year, depending on meteorological conditions. The general flows of water during normal operation and during purge periods are presented schematically in Figure VII-17.

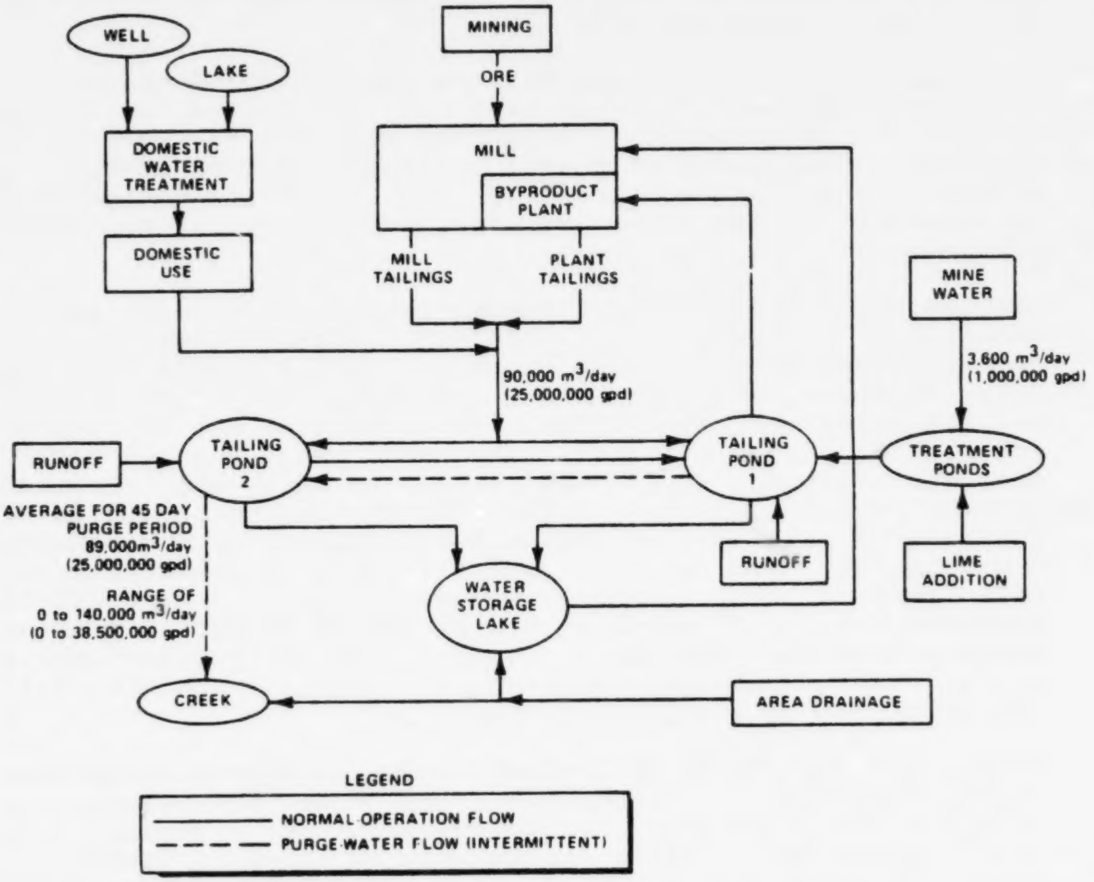
In addition to snow-melt influx, water is drawn for the system from a well and a small lake (domestic water supply), mine drainage, and collection structures on a number of area streams when needed. Diversion structures are currently being greatly expanded and modified to provide diversion for most of the area runoff around existing and new tailing ponds. Drainage from a number of old mine workings (not owned by the operator of mine 6102) to the tailing-disposal area has complicated the diversion process. Drainage of low quality is being segregated and channeled into the tailing ponds rather than being diverted to the receiving stream. Water leaves the system through consumptive losses in the mill, evaporation from pond areas, seepage, and the aforementioned discharge during peak runoff. With the completion of diversion structures, discharge will be substantially reduced, and will occur only during a two month spring runoff period.

Within the water system, a complex pattern of pumping and gravity flow is used to provide water treatment and recycle. Three major impoundments, as well as a number of smaller impoundments and settling ponds, are currently involved.

A large man-made lake serves as the major holding basin for water to be recycled to the mill. It receives decant water from two active tailing ponds. From this lake, water is pumped to two 7,570-cubic-meter (2,000,000-gallon) holding tanks at the mill site.

Two mill tailing ponds, 303 hectares (750 acres) and 182 hectares (450 acres) in area, are interconnected and also connected to the mill water reservoir by a series of decant structures.

Figure VII-17. WATER-FLOW SCHEMATIC DIAGRAM FOR MILL 6102



WELL
LAKE
DOMESTIC WATER TREATMENT
DOMESTIC USE
MINING
ORE
MILL
BYPRODUCT PLANT
MILL TAILINGS
PLANT TAILINGS
MINE WATER
90,000 m³/day (25,000,000 gpd)
3,600 m³/day (1,000,000 gpd)
RUNOFF
TAILING POND 2
TAILING POND 1
TREATMENT PONDS
AVERAGE FOR 45 DAY PURGE PERIOD 89,000m³/day (25,000,000 gpd)
RANGE OF 0 to 140,000 m³/day (0 to 38,500,000 gpd)
RUNOFF
LIME ADDITION
WATER STORAGE LAKE
CREEK
AREA DRAINAGE
LEGEND
NORMAL OPERATION FLOW
PURGE-WATER FLOW (INTERMITTENT)

Tailing ponds have not been treated with any deliberate sealant. Seepage through the toe dam is collected in impoundment ponds and pumped back up to the tailing ponds. The allowance of seepage in this fashion is intended to limit hydrostatic pressures on the dam and enhance safety.

Mine water is treated by lime-slurry addition in lagoons before being pumped to the tailing pond and entry into the mill water system. About 1,364 kg (3,000 lb) per day of lime are consumed in treating the average mine water flow of 3,600 cubic meters/day (700 gpm).

Construction of a major new tailing pond is presently underway. This pond will have an area of 485 hectares (1,200 acres) and is expected to serve the mill for the next 35 to 50 years. Concurrent with this tailing-pond construction, a number of supporting projects are underway, including development of the extensive diversion structures mentioned previously.

Samples were collected at a number of points in the water-management system, both during normal total-recycle operation and during spring runoff. Spring-runoff samples were, however, atypical due to ice damage to a decant tower shortly before the site visit. This resulted in a sudden and rapid purge of the tailing pond. Only a small decand flow was occurring during the visit, and this was recycled to the tailing pond. Table VII-31 presents results of analyses of tailing-pond decant during normal zero-discharge operation and also shows the concentration of pollutants in mill recycle water after further settling. Table VII-32 presents results of sampling during spring runoff as well as company data for discharge quality and calculated waste loads. Raw waste characteristics and loadings for mill 6102 are presented in Section V.

Comparison of data in Tables VII-31 and VII-32 shows that appreciably higher concentrations of many pollutants are observed in the effluent streams during purge periods than are found in the tailing ponds during normal operation. This flushing effect--presumably, resulting from flows higher than the design capacity of the treatment system--negates, to a large extent, the benefits derived from recycle in terms of removal of many pollutants. As a result, yearly average effluent loads per ton of ore are, in most cases, comparable to those achieved at mill 6101 without recycle from the tailing pond. Significant advantage is seen in the recycle system, however, in the removal of pollutants such as TDS, which are not effectively

TABLE VII-31. CHEMICAL COMPOSITION AND CALCULATED WASTE LOAD FOR MILL 6102 TAILING-POND SURFACE WATER, WITH ANALYTICAL DATA FOR MILL-RESERVOIR WATER

PARAMETER	TAILING-POND SURFACE WATER					MILL-RESERVOIR WATER
	CONCENTRATION (mg/ ℓ)	TOTAL WASTE		CALCULATED WASTE LOAD per unit ore milled		CONCENTRATION (mg/ ℓ)
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons	
TSS	–	–	–	–	–	14
TDS	1,940	175,000	390,000	4,500	9,000	1,936
Oil and Grease	0	0	0	0	0	2.0
COD	11.9	1,070	2,400	27	54	19.8
As	0.01	0.90	2.0	0.023	0.046	0.01
Cd	< 0.01	< 0.90	< 2	< 0.02	< 0.05	< 0.01
Cu	0.04	3.6	7.9	0.092	0.18	0.20
Mn	3.2	288	630	7.4	15	4.3
Mo	12.5	3,600	7,900	92	180	–
Pb	< 0.02	< 1.8	< 4	< 0.05	< 0.09	< 0.02
V	< 0.5	< 45	< 100	< 1	< 2	< 0.5
Zn	0.10	9.0	20	0.23	0.46	0.47
Fe	2.05	180	400	4.6	9.2	4.5
Cyanide	0.02	1.8	4.0	0.046	0.092	0.04
Fluoride	14.9	1,340	2,900	34	68	20

TABLE VII-32. CHEMICAL COMPOSITION AND WASTE LOADING FOR DISCHARGE AT MILL 6102 (COMPANY DATA)

PARAMETER	CONCENTRATION (mg/ ℓ)	AVERAGE TOTAL WASTE FOR 45 DAY DISCHARGE PERIOD		AVERAGE WASTELOAD FOR 45 DAY DISCHARGE PERIOD per unit ore milled	
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons
TSS	137	12,000	27,000	310	620
TDS	1,633	150,000	320,000	3,700	7,500
COD	21	1,900	4,100	48	97
Oil and Grease	1	81	180	2.1	4.2
Total Fe	9.96	890	1,900	23	45
Total Mn	4.40	390	890	9.7	19
Zn	0.58	52	110	1.3	2.6
Cd	< 0.01	< 0.8	< 2	< 0.02	< 0.05
Mo	19.09	1,700	3,700	44	88
Cu	0.125	11	25	0.29	0.58
Cyanide	–	–	–	–	–
Fluoride	20.7	1,900	4,100	48	97

removed by the standard alkaline precipitation and settling treatment. Significantly greater advantage is expected to be realized from the recycle system as further development of diversion ditches appreciably decreases the volume of purge flow, resulting in improvements in quality, as well as decreased quantity, of effluent.

A portion of the mill effluent stream was treated in an ion-exchange pilot plant for molybdenum removal. The pulsed-bed pilot plant was operated extensively, producing an effluent consistently below 2 mg/l molybdenum concentration. Representative feed and effluent analysis data are shown below.

Molybdenum Ion Exchange Pilot Plant Data (1975)

Date	Concentration (mg/l) Feed	Effluent	Eluate
7-25	20.5	1.18	16,140
7-29	23.0	0.91	16,045
7-30	22.4	1.38	16,568
8-1	24.4	1.76	18,090
8-2	19.5	1.14	12,930
8-6	22.0	1.38	17,484
Average	22.0	1.29	16,230

A saleable molybdenum product may be recovered from the highly concentrated eluate stream, offsetting the costs of the ion-exchange operation. Early results indicated that breakeven--or even profitable--operation may be possible.

Mill 6106. This operation is engaged in the processing of nickel ore (garnierite) to produce ferronickel. Mill 6106 is located in Oregon and processes approximately 4,535 metric tons (5,000 short tons) of ore per day. This mill is representative of physical ore processors.

Water used in beneficiation and smelting of nickel ore at mill 6106 is extensively recycled, both within the system and from external water treatment. The bulk of the plant water use is in the smelting operation, since wet-beneficiation processes are not practiced. Water is used for ore-belt washing, in scrubbers on ore driers, in cooling, and for slag granulation. Water recycled within the process is treated in two settling ponds, arranged in series. The first of these, 4.8 hectares (12 acres) in area, receives a process water influx of 12.5 cubic meters

(3,300 gallons) per minute, of which 9.9 cubic meters (2,600 gallons) per minute are returned to the process. Overflow to the 5.2-hectare (13-acre) second pond amounts to 1.2 cubic meters (320 gallons) per minute. This second pond also receives runoff water from the open-pit mine site which is highly seasonal, amounting to zerc for approximately six months and reaching as high as 2,200 cubic meters (580,000 gallons) per day during the (winter) rainy season. The lower pond has no surface discharge during the dry season, inputs being balanced by evaporation and subsurface flow to a nearby creek. A sizeable discharge results from runoff inputs during wet weather. Average discharge volume over the year amounts to 460 cubic meters (120,000 gallons) per day.

This mill was visited during a period of zero discharge, and samples collected reflect this condition. Samples were collected from the influent to the first settling pond and from its overflow, as well as from the surface waters of the lower settling pond. Analytical data for the influent to the treatment system are reported in Section V. Data for influent to the second settling pond from the first pond, and for its surface waters, are presented in Tables VII-33 and VII-34. In general, the analyses of these samples were in agreement with data furnished by the company for corresponding conditions. In Table VII-35, average effluent loads based on company data for the period of discharge are furnished. Since influent from mine runoff could not be determined, no accurate measure of treatment effectiveness is available. It is evident, however, that effluent loads are quite low.

As Table VII-33 shows, the first settling pond alone is highly effective in reducing concentrations of heavy metals in the effluent stream. The recycle of substantial portions of the process water delivered to this pond still further diminishes the effluent load. The surface discharge from the second settling pond is lower in most metals than the overflow from the first pond, even though substantial mine runoff also enters the second pond. The alkaline pH (average of 8.7) prevalent in these basins enhances treatment effectiveness in retaining heavy metals.

Mill 6107. At this operation, vanadium is recovered from non-radioactive ore in a hydrometallurgical operation involving salt roasting, leaching, solvent extraction, and precipitation. Approximately 1,140 metric tons (1,250 short tons) of ore are processed per day, requiring the use of 7,600 cubic meters (1,900,000 gallons) of process water. At

TABLE VII-33. CHEMICAL COMPOSITION AND TREATED WASTE LOADS FOR OVERFLOW FROM FIRST SETTLING POND AT MILL 6106

PARAMETER	CONCENTRATION (mg/ℓ)	TOTAL WASTE		WASTE LOAD per unit ore milled	
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons
Cd	< 0.01	< 0.02	< 0.04	< 0.004	< 0.009
Co	< 0.05	< 0.08	< 0.02	< 0.02	< 0.04
Cu	< 0.02	< 0.03	< 0.07	< 0.007	< 0.01
Fe	0.95	1.4	3.1	0.31	0.62
Mn	0.02	0.03	0.066	0.0066	0.013
Ni	0.07	0.11	0.24	0.024	0.048
Pb	< 0.1	< 0.2	< 0.4	< 0.04	< 0.09
Zn	0.03	0.045	0.099	0.0099	0.020

TABLE VII-34. CHARACTERISTICS OF SURFACE WATER FROM SECOND SETTLING POND AT MILL 6106

PARAMETER	CONCENTRATION (mg/ℓ)	TOTAL WASTE		WASTE LOAD			
				per unit ore milled		per unit product	
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons	kg/1000 metric tons	lb/1000 short tons
TSS	6.2	2.9	6.4	0.64	1.3	35	69
TDS	184	85	187	18.7	37	1,000	2,000
Oil and Grease	2.7	1.2	2.6	0.26	0.53	14	29
Cd	< 0.005	< 0.002	< 0.004	< 0.0004	< 0.0009	< 0.02	< 0.05
Cu	< 0.02	< 0.009	< 0.02	< 0.002	< 0.004	< 0.1	< 0.2
Fe	0.47	0.22	0.48	0.048	0.097	2.6	5.2
Mn	< 0.02	< 0.009	< 0.02	< 0.002	< 0.004	< 0.1	< 0.2
Ni	0.03	0.014	0.031	0.0031	0.0062	0.18	0.36
Pb	< 0.05	< 0.02	< 0.04	< 0.04	< 0.09	< 2	< 5
Zn	0.009	0.0041	0.0090	0.0009	0.0018	0.05	0.10

TABLE VII-35. CHEMICAL COMPOSITION AND TREATED WASTE LOADS FROM FINAL EFFLUENT FOR MINE/MILL 6106 DURING RAINY SEASON (COMPANY DATA)

PARAMETER	CONCENTRATION[†] (mg/ℓ)	TOTAL WASTE*		WASTE LOAD	
				per unit ore processed*	
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons
TSS	30.8	14	31	3.1	6.2
TDS	165	76	170	17	34
Cu	0.003	0.0014	0.0031	0.00031	0.00062
Fe	0.12	0.055	0.12	0.012	0.024
Mn	0.007	0.0032	0.0070	0.0007	0.0014
Ni	0.038	0.017	0.037	0.0037	0.0074
Zn	0.006	0.0028	0.0062	0.00062	0.0012

[†] Approximate average for periods of discharge

*Yearly averages

TABLE VII-36. CHEMICAL COMPOSITION AND WASTE LOADING FROM AREA RUNOFF AND RECLAMATION-POND SEEPAGE AT MILL 6107 (COMPANY DATA)

PARAMETER	CONCENTRATION (mg/ℓ)	TOTAL WASTE		WASTE LOAD	
				per unit ore milled	
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons
pH	6.4*	–	–	–	–
TSS	10	52	104	46	92
TDS	1,705	8,900	18,000	7,800	16,000
Oil and Grease	< 1	< 5	<10	< 4	< 9
COD	6	31	62	27	54
Ammonia	1.0	5.2	10.4	4.6	9.2
As	0.02	0.10	0.21	0.088	0.18
Cd	< 0.01	< 0.05	< 0.1	< 0.04	< 0.09
Cr	< 0.01	< 0.05	< 0.1	< 0.04	< 0.09
Cu	< 0.01	< 0.05	< 0.1	< 0.04	< 0.09
Mn	5.8	30	60	26	53
Mo	< 0.1	< 0.5	< 1	< 0.4	< 0.9
Pb	< 0.01	< 0.05	< 0.1	< 0.04	< 0.09
Zn	0.04	0.21	0.42	0.19	0.38
Fe	< 0.1	< 0.5	< 1	< 0.4	< 0.9
Fluoride	< 1	< 5	<10	< 4	< 9

*Value in pH units

this operation, representative of the leaching-mill subcategory, three distinct mill wastewater streams are discharged.

Two of three effluents associated with mill 6107 contain primarily noncontact water. One is primarily spring water and natural drainage, with some infiltration from a process-water reclamation pond and occasional spills of process water. The other receives non-contact cooling water. Treatment of these waste streams consists only of segregation from process water and area runoff. Analytic data for these effluents are presented in Tables VII-36 and VII-37.

The main wastewater stream from mill 6107 receives inputs from several process units and air-pollution control devices, as well as contaminated drainage from the mill area. Essentially all streams entering this waste stream bear very high concentrations of dissolved salts, as well as a variety of other contaminants, including ammonia and various heavy metals. The complex system of inputs and treatment and holding ponds feeding this discharge is illustrated in Section V. The main process effluent from washing, leaching, and solvent extraction is treated by ammonia addition prior to discharge to a 5.3-hectare (13-acre) holding pond, where it is joined by scrubber bleed water from ore dryers and treated sanitary wastewater, both of which have first been treated for solids removal in a holding pond. Bleed water from a roaster/scrubber is treated by settling in a primary pond before delivery to a 2.8-hectare (7-acre) holding pond, adjacent to that containing process effluent. Discharge from these two ponds is staged to avoid the formation of calcium sulfate precipitates, which would result from their combination. Further, discharge is adjusted by impoundment in accordance with flow in the receiving water to comply with permit stipulations on the maximum allowable chloride increase in the receiving water (25 mg/l). The volume of this effluent is limited somewhat by recycle of water from the tailing pond to the washing circuit, recycle within the solvent-extraction/precipitation operation, and recycle of scrubbing water to the greatest extent practical. In general, further reuse of water is limited by the extremely high concentrations of dissolved solids in the effluent water.

Data for the process wastewater after ammonia treatment, and for the drier scrubber bleed after solids removal, are presented in Tables VII-38 and VII-39. The two waste streams are combined in one holding pond for staged discharge.

TABLE VII-37. CHEMICAL COMPOSITION AND WASTE LOADING FOR COOLING-WATER EFFLUENT AT MILL 6107 (COMPANY DATA)

PARAMETER	CONCENTRATION (mg/ℓ)	TOTAL WASTE		WASTE LOAD per unit ore milled	
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons
pH	7.2*	–	–	–	–
TSS	20	42	92	37	74
TDS	695	1,500	3,300	1,300	2,600
Oil and Grease	< 1	< 2	< 4	< 2	< 4
COD	15	32	70	28	56
Ammonia	10	21	46	18	38
As	0.010	0.021	0.046	0.018	0.036
Cd	< 0.01	< 0.02	< 0.04	< 0.02	< 0.04
Cr	< 0.01	< 0.02	< 0.04	< 0.02	< 0.04
Cu	< 0.01	< 0.02	< 0.04	< 0.02	< 0.04
Mn	0.54	1.1	2.4	0.97	1.9
Mo	< 0.10	< 0.2	< 0.4	< 0.2	< 0.4
Pb	< 0.01	< 0.02	< 0.04	< 0.02	< 0.04
Zn	0.18	0.38	0.84	0.34	0.67
Fe	< 0.10	< 0.2	< 0.4	< 0.2	< 0.4
Fluoride	< 1	< 2	< 4	< 2	< 4

*Value in pH units

TABLE VII-38. CHEMICAL COMPOSITION AND WASTE LOADING FOR PROCESS EFFLUENT AFTER AMMONIA TREATMENT AT MILL 6107

PARAMETER	CONCENTRATION (mg/ℓ) IN WASTEWATER	TOTAL WASTE		WASTE LOAD per unit ore processed	
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons
pH	8.3*	–	–	–	–
TDS	40,284	85,000	190,000	75,000	150,000
Oil and Grease	5	11	24	10	20
COD	443	930	2,000	820	1,640
As	0.13	0.27	0.59	0.24	0.48
Cd	0.039	0.082	0.18	0.072	0.144
Cr	0.2	0.42	0.92	0.37	0.74
Cu	0.13	0.27	0.59	0.24	0.48
Mn	52	109	240	96	192
Mo	< 0.1	< 0.2	< 0.4	< 0.2	< 0.4
Pb	< 0.05	< 0.1	< 0.2	< 0.1	< 0.2
V	31.5	66	145	58	116
Zn	0.47	0.99	2.2	0.87	1.74
Fe	0.3	0.63	1.4	0.56	1.12
Fluoride	4.55	9.6	21	8.5	17

*Value in pH units

TABLE VII-39. CHEMICAL COMPOSITION AND WASTE LOADING FOR DRIER SCRUBBER BLEED WATER AFTER SETTLING TREATMENT AT MILL 6107

PARAMETER	CONCENTRATION (mg/ℓ) IN WASTEWATER	TOTAL WASTE		WASTE LOAD per unit ore processed	
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons
pH	7.7*	–	–	–	–
TDS	10,852	10,000	22,000	8,800	16,600
Oil and Grease	3	2.8	6.2	2.5	5
COD	34.27	32	70	28	56
As	< 0.07	< 0.07	< 0.15	< 0.06	< 0.12
Cd	< 0.005	< 0.05	< 0.1	< 0.004	< 0.008
Cr	0.1	0.094	0.21	0.083	0.166
Cu	0.08	0.075	0.17	0.066	0.122
Mn	13.0	12	26	11	22
Mo	< 0.1	< 0.09	< 0.2	< 0.08	< 0.16
Pb	< 0.05	< 0.05	< 0.1	< 0.04	< 0.08
V	37.5	35	77	31	62
Zn	0.17	0.16	0.35	0.14	0.28
Fe	0.75	0.71	1.6	0.63	1.26
Fluoride	1.2	1.1	2.4	0.97	1.94

*Value in pH units

Since this pond was not discharging during sampling, only company data are presented in Table VII-40.

Table VII-41 presents data for treated effluent from the holding pond receiving wastewater from roaster/scrubbers after primary settling. Table VII-42 presents additional company data for the same discharge. Average characteristics of total process effluent (company data) are presented in Table VII-43.

Mill 6104. At mill 6104, a complex ore is processed by flotation and leaching operations to yield molybdenum and copper concentrates and ammonium paratungstate. The mill is located in California. Mill wastewater is treated by lime addition to a pH of 9.5 and subsequent impoundment in a tailing pond, from which clarified water exits by percolation and evaporation. Treatment practiced on segregated waste streams from the leaching and solvent-extraction processes is representative of advanced treatment applicable to leaching operations. Waste streams from chemical processing of scheelite flotation concentrates are treated by distillation in a two-stage evaporator/crystallizer and by stripping with air for ammonia removal prior to combination with tails from other operations for liming and delivery to the tailing ponds.

The air stripper operating at this facility treats approximately 0.27 cubic meters per minute (70 gal per minute) of ammonia-laden wastewater in a packed tower achieving an average of 70% removal of ammonia. The ammonia which is removed is currently released to the atmosphere. Repeated sampling at this site showed stripper performance to be variable--apparently, depending strongly on pH control of the feed solution. Typical feed and effluent ammonia concentrations are 300 mg/l and 80 mg/l, respectively.

Samples of the solvent-extraction effluent and the precipitation waste before treatment were not obtained. Since there was no surface discharge, and since there was no pool of water in the tailing pond at the time of the visit to this site, no sample of clarified mill discharge water could be obtained. Limitations met by this discharge may be assumed to be indicative of its quality and are tabulated below.

TABLE VII-40. CHEMICAL COMPOSITION AND WASTE LOADING FOR HOLDING-POND EFFLUENT (PROCESS WATER AND DRIER SCRUBBER BLEED) AT MILL 6107 (COMPANY DATA)

PARAMETER	CONCENTRATION (mg/ℓ) IN WASTEWATER	TOTAL WASTE		WASTE LOAD per unit ore processed	
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons
Ammonia	2,030	6,500	14,000	5,600	11,200
Ca	450	1,400	3,100	1,200	2,400
Cd	0.08	0.26	0.57	0.23	0.46
Cu	0.23	0.73	1.6	0.64	1.28
Mn	38	120	260	110	220
Mo	16	51	110	45	90
V	31	99	220	87	174
Zn	0.83	2.7	5.9	2.4	4.8
Ni	0.96	3.1	6.8	2.7	5.4
Fe	0.23	0.73	1.6	0.64	1.28
Sulfate	12,200	39,000	86,000	34,000	68,000
Chloride	7,800	25,000	55,000	22,000	44,000

TABLE VII-41. CHEMICAL COMPOSITION AND WASTE LOADING FOR ROASTER SCRUBBER BLEED WATER AFTER SETTLING AT MILL 6107

PARAMETER	CONCENTRATION (mg/ℓ) IN WASTEWATER	TOTAL WASTE		WASTE LOAD per unit ore processed	
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons
pH	7.9*	–	–	–	–
TSS	121**	209	460	180	360
TDS	57,690	100,000	220,000	88,000	176,000
Oil and Grease	3	5.2	11	4.6	9.2
COD	1,859	3,200	7,000	2,800	5,600
As	< 0.07	< 0.1	< 0.3	< 0.09	< 0.18
Cd	< 0.005	< 0.009	< 0.02	< 0.008	< 0.016
Cr	0.2	0.35	0.77	0.31	0.62
Cu	< 0.03	< 0.05	< 0.1	< 0.04	< 0.08
Mn	5.5	9.5	21	8	16
Mo	< 0.1	< 0.2	< 0.4	< 0.2	< 0.4
Pb	< 0.05	< 0.09	< 0.2	< 0.08	< 0.16
V	15	26	57	23	46
Zn	5.95	10	23	8.8	17.6
Fe	0.25	0.43	0.95	0.38	0.76
Fluoride	6.0	10	23	8.8	17.6

* Value in pH units

** Company data indicates this should be ≃ 30 mg/ℓ (Waste loads are correspondingly high)

TABLE VII-42. CHEMICAL COMPOSITION AND WASTE LOADING FOR ROASTER SCRUBBER BLEED WATER AFTER SETTLING AT MILL 6107 (COMPANY DATA)

PARAMETER	CONCENTRATION (mg/ℓ) IN WASTEWATER	TOTAL WASTE		WASTE LOAD per unit ore processed	
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons
Ammonia	360	620	1,400	550	1,100
Ca	26,000	45,000	99,000	40,000	80,000
Cd	0.42	0.73	1.6	0.64	1.28
Cu	0.31	0.54	1.2	0.48	0.96
Mn	11	19	42	17	34
Mo	1.1	1.9	4.2	1.7	3.4
V	14	24	53	21	42
Zn	8.4	15	33	13	26
Ni	1.0	1.7	3.7	1.5	3.0
Fe	0.93	1.6	3.5	1.4	2.8
Sulfate	500	820	1,900	760	1,420
Chloride	36,000	62,000	140,000	55,000	110,000

TABLE VII-43. CHEMICAL COMPOSITION AND WASTE LOADING FOR AVERAGE TOTAL PROCESS EFFLUENT AT MILL 6107 (COMPANY DATA)

PARAMETER	CONCENTRATION (mg/ℓ) IN WASTEWATER	TOTAL WASTE		WASTE LOAD per unit ore processed	
		kg/day	lb/day	kg/1000 metric tons	lb/1000 short tons
pH	6.7*	–	–	–	–
TSS	180	890	2,000	780	1,560
TDS	44,000	220,000	480,000	190,000	380,000
Oil and Grease	< 1	< 5.0	< 10	< 4	< 8
COD	70	340	750	300	600
Ammonia	1,200	5,900	13,000	5,200	10,400
As	0.020	0.098	0.22	0.09	0.18
Cd	0.30	1.5	3.3	1.3	2.6
Cr	0.090	0.44	0.97	0.39	0.78
Cu	0.26	1.3	2.9	1.1	2.2
Mn	28	140	310	120	240
Mo	11	54	120	48	96
Pb	< 0.1	< 0.5	< 1	< 0.4	< 0.8
Zn	4.00	20	44	18	36
Fe	0.50	2.5	5.5	2.2	4.4
Fluoride	1	4.9	11	4.3	8.6

*Value in pH units

Parameter	Concentration (mg/l)
Sodium	600
Chloride	1000
Sulfate	1000
Total Nitrogen (Organic, NH_3, WO_3)	5
Nitrate	2

These values are consistent with the observed 2,290 mg/l TDS content of the combined tailing stream (See Waste Characteristics, Section V), reflecting the substantial removal of dissolved salts--especially, sodium sulfate--from the effluent.

Mercury Ores

Historically, water has found little use in the mercury-ore mining and dressing industry. In the past, the mined ore was primarily fed directly into a retort or furnace, and the mercury was recovered by roasting. When beneficiation has been employed, it has normally been limited to crushing and/or grinding. As a result, water-treatment technology or facilities have not been typically required in this industry.

Mining Operations. Water is not used in mercury mining operations and is discharged only where it accumulates as a result of seepage or precipitation. When mines are not located adjacent to a mill, or when their effluents (if any) are to be segregated from the mill wastewater, it will be necessary to discharge these waters, unless total impoundment is possible. Treatment of this wastewater is necessary for removal of suspended solids and heavy metals. The mercury ion is best treated for removal by sulfide precipitation. Other technologies for the removal of heavy-metal waste constituents are the chemical precipitation and/or flocculation methods and settling ponds, which have been discussed previously in this section.

Milling Operations. Mercury ore can be concentrated by gravity methods and by froth flotation. However, these methods have not been employed extensively, since direct retorting of the ore is an efficient and effective method for recovering mercury. In addition, most mercury ores are not amenable to gravity separation, since mercury minerals tend to be crushed finer than the gangue, with resultant excessive loss of these minerals in the slimes. However, as lower-grade mercury ores become mined, it is expected that beneficiation processes will become increasingly important and necessary in this industry.

Mill 9201. This operation is located in the state of California. Operation of this mill is seasonal, with closure of the mine/mill during the rainy season (winter), when muddy roads make access difficult. A sandstone ore containing cinnabar (HgS) is mined from an open pit and brought to the mill. During 1973, 30,000 short tons (27,210 metric tons) of ore were milled by gravity methods to produce a cinnabar concentrate. No discharge results from the mine.

This mill operates on a total-recycle system, with no discharge resulting. Water is used in a gravity-separation process, and the mill tailings are discharged at a rate of 1,665 cubic meters (436,000 gallons) per day to a 1-hectare (2.5-acre) tailing pond. Seperan NP-10, a flocculant, is added to the waste stream to increase solids settling. Clarified pond water is decanted and returned to the mill for reuse. About 16 cubic meters (4,300 gallons) per day of makeup water are required, and this is obtained from a nearby reservoir.

The efficiency of the treatment system is presented in Table VII-44. No waste loadings have been computed, because no discharge results from this operation.

Mine/Mill 9202. This operation, located in Nevada, has been actively producing only since early 1975. The ore, which consists of cinnabar (HgS) and corderoite ($Hg_3S_2Cl_2$), disseminated in ancient lake-bed sediments (primarily clays), is concentrated by flotation. This ore is mined by open-pit methods, and at present, no water accumulates in the mine which would necessitate a discharge.

Mill tailings are presently impounded in four 20-hectare (50-acre) ponds for retention of solids and evaporation of wastewater. The operators of this mill initially proposed to recycle clarified decant from these ponds back to the mill. However, difficulty in obtaining a clarified decant has been experienced, and, as a result, recycle has not yet been feasible on a large scale. The problem stems from the

TABLE VII-44. CHEMICAL COMPOSITIONS OF MILL WASTEWATER AND TAILING-POND SURFACE WATER AFTER TREATMENT AT MINE/MILL 9201 (NO DISCHARGE, RECYCLE OF TREATED WATER)

PARAMETER	CONCENTRATION (mg/ℓ)	
	MILL WASTEWATER	TAILING-POND DECANT
pH	6.5*	6.5*
TSS	154,000	76
TDS	290	144
COD	42.79	27.23
Oil and Grease	< 1	2
SiO_2	9.8	9.3
Al	10.4	0.5
Cd	< 0.005	< 0.005
Cr	0.04	0.02
Cu	< 0.02	< 0.02
Total Fe	< 0.5	0.87
Pb	< 0.1	< 0.1
Total Mn	50.0	0.10
Hg	–	0.125
Ni	0.68	0.10
Sr	0.60	0.10
Zn	0.14	0.03
Sb	< 0.5	< 0.5
Mo	< 0.2	< 0.2
Fluoride	0.61	0.83
Sulfate	100	75

*Value in pH units

presence of montmorillonite clay in the ore body. This material becomes suspended during milling activities and is very slow to settle. Flocculants have been used to aid settling but have not, to date, been successful. Reuse of the pond water having the quality presently obtained would reportedly result in a lower percentage of recovery, lower-grade concentrate, and lower daily rate of production (less ore milled/day). For these reasons, recycle has not been attempted on a large scale.

The quality of the wastewater prior to and following settling is presented in Table VII-45. No waste loadings have been computed, as no discharge results from this operation.

Uranium, Radium, and Vanadium Ores

The discussion that follows describes treatment and control technology in current use in the uranium, radium, and vanadium (byproduct recovery under NRC licensing) ore mining and dressing industry. Aspects of treatment and control which are characteristic of this category are described.

Mining Operations. Uranium mining in the U.S. is conducted primarily in the arid states. Approximately 60 percent of the facilities contacted in the course of this study indicated that they have no discharge. Where it is practical, mine wastewater is used as process feed water for milling. It then becomes a mill effluent and is impounded, and subsequently is lost to evaporation and seepage. At the operations employing the best treatment and control technology in this industry, uranium values are frequently extracted from minewater by ion exchange (IX) methods. In addition, where dry mines are proximate to mines discharging wastewater, the discharge is often recycled to the dry mines to effect in-situ leaching. Evaporation and other losses in this process often reduce water volume to a point where no discharge results. Further treatment of wastewater destined for natural waterways always includes settling.

High values of Ra226 observed in mine wastewater indicate that coprecipitation treatment is necessary to reduce radium values to acceptable values. Values of Ra226 in mine wastewater currently range from approximately 100 to 400 picocuries per liter, while technology currently being employed in mill wastewater treatment nearly always attains reduction to a level of below 3 picocuries per liter; under favorable conditions existing in well-designed treatment systems, levels of 1 picocurie per liter have been obtained.

TABLE VII-45. CHARACTERIZATION OF MILL WASTEWATER AND TAILING-POND SURFACE WATER FOLLOWING SETTLING AT MINE/MILL 9202

PARAMETER	CONCENTRATION (mg/ℓ)	
	MILL WASTEWATER	TAILING-POND DECANT*
pH	8.2†	8.4†
TSS	–	–
COD	–	94
Cd	0.42	< 0.005
Cr	3.6	0.015
Co	1.7	< 0.05
Cu	1.3	0.26
Fe	2,880	1.7
Pb	0.58	0.02
Mn	7.0	0.034
Ni	2.4	0.021
Sb	3.76	0.23
Zn	1.1	0.10
Hg	27.5	0.014

*Sample collected from pond at point of decant when decant of water for recycle is employed.

†Value in pH units.

In addition, similar technology applied to a mine has demonstrated reduction to less than 3 pCi/l regularly obtainable, with levels below 1 pCi/l under favorable conditions.

To employ treatment technology recommended here for radium reduction, in mine wastewaters, it may sometimes be necessary to add sulfate ion to the wastewater stream to allow coprecipitation with barium chloride. If ferrous sulfate is added at a level of 100 mg/l, some molybdenum is also coprecipitated with ferric hydroxide, and sulfate ion is liberated to effect radium coprecipitation.

Mine 9401. This operation currently obtains uranium ore from four underground mines in New Mexico, one of which contributes a significant amount of mine water to adjacent mines after treatment by ion exchange (for uranium extraction) for *in-situ* leaching. The total flow in the ion-exchange plant is 9,300 cubic meters (2,455,200 gallons) per day. Evaporation losses in surface distribution channels apparently cancel the excess influx from the one wet mine, so no discharge results. If there were a discharge from the ion exchange system, this discharge would exhibit high levels of suspended solids (530 mg/l) and COD (750 mg/l).

The ion-exchange process at this operation illustrates that an IX system which is optimized for one particular ion (e.g., uranyltrisulfuric ion) is relatively ineffective for removing even similar ions. As shown in the table below, only vanadium follows uranium in being extracted.

Element	In	Out
U	25	1
As	0.03	0.04
Pb	0.02	0.11
V	1.0	less than 0.5
Fe	0.47	0.51
Mo	0.5	0.77
Be	0.01	0.01
Al	0.55	0.55
B	0.15	0.19
Ca	93	96
Mg	45	45
K	25	25
Na	200	200
Sr	0.87	0.124
Zn	0.034	0.064

However, in this case, uranium and vanadium are reduced to levels of 1 mg/l or less. With some compromises in treatment efficiency for uranium and vanadium, other metals can be removed.

Mine 9402. A group of several mines discharging 11,500 cubic meters (3,036,000 gallons) of water per day is located near a mill which uses approximately two-thirds of the mine discharge as mine process water. This operation is also located in New Mexico. Two types of treatment are used. At one mine, mine water is treated for suspended-solids removal by a series of three settling ponds and then is discharged. Table VII-46 presents the chemical compositions of raw and treated wastewaters resulting from this mine.

A second group of mines feeds a treatment system consisting of an ion-exchange plant (for removal of uranium values). Discharge from the ion-exchange plant splits with approximately 23 percent being discharged and the remainder entering a holding pond to be used as mill make-up water. (See Figure V-34b.)

Initial concentrations varying from 2 to 12 mg/l of U_3O_8 were treated by use of an eight-column anionic-exchange system, which recovers 98 percent of the influent uranium. At lower concentrations, this process is known to be less effective than at higher concentration. An example of this loss efficiency can be cited for the case of mercury removal by ion exchange methods, as shown in Figure VII-18. The fact that uranium shows a similar behavior is illustrated by the data points for uranium that have also been plotted on this graph. Additional data on the efficiency of IX processes are available to members of the industry. These data currently are proprietary, for competitive reasons.

Table VII-47 presents the results of treatment by ion exchange and settling at mine 9402(002).

Milling Operations. Treatment for suspended-solid removal, neutralization of pH, precipitation of hazardous pollutants, coprecipitation of parameters in very low concentrations, and for the recovery of values exists in milling operations of the uranium industry. Some treatment is used to permit discharge, while, in most instances, treatment facilitates recycle and/or impound. Approximately 90 percent of the uranium milling industry has no point discharges. Two of the remaining milling operations have lateral seepage from tailing impoundments that is collected and discharged. One operation is currently modifying its entire process to

TABLE VII-46. CHEMICAL COMPOSITIONS OF RAW AND TREATED WASTEWATERS AT MINE 9402 (001)

PARAMETER	CONCENTRATION (mg/ℓ)	
	RAW WASTEWATER	TREATED WASTEWATER
pH	8.1*	7.4*
TSS	289	17
COD	< 10	15.9
TOC	45	19.5
As	0.02	0.02
Cd	–	0.003†
Cr	–	0.01†
Cu	< 0.5	0 to 0.01†
Hg	–	0.001†
Mo	0.5	0.8
Ni	–	0.04†
Pb	0.13	0.1
V	2.1	1.7
Zn	–	0.002†
Ra	230**	65**
U	4.14	1.1

*Value in pH units †Company data **Value in picocuries/ℓ

Figure VII-18. ION EXCHANGE FOR MERCURY AND URANIUM AT LOW LOADINGS AND CONCENTRATIONS

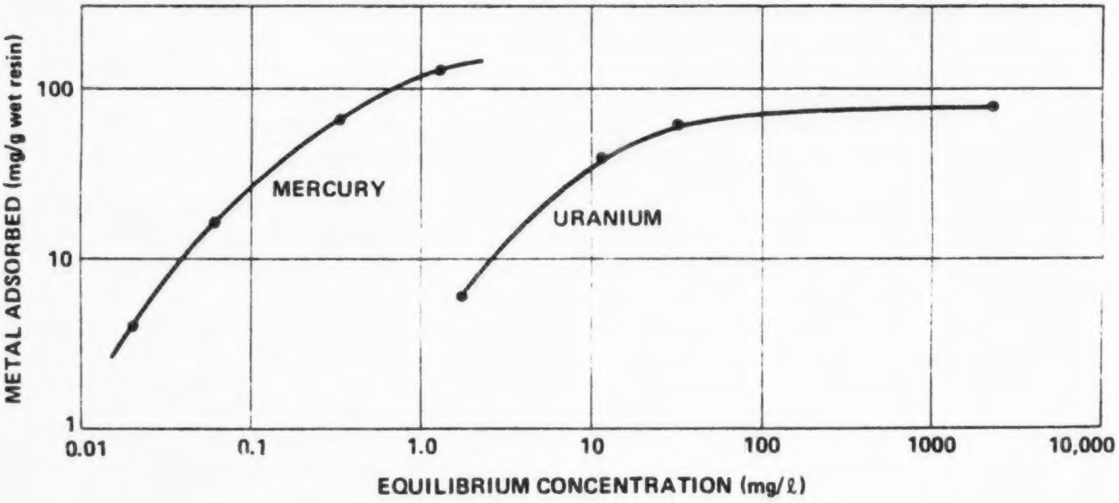


TABLE VII-47. CHEMICAL COMPOSITIONS OF RAW AND TREATED WASTEWATERS AT MINE 9402 (002)

PARAMETER	CONCENTRATION (mg/ℓ)	
	RAW WASTEWATER	DISCHARGE FROM TREATMENT (IX)
pH	7.7†	8.1†
TSS	–	–
COD	734	405
TOC	20.5	20.5
As	< 0.01	0.02
Cd	< 0.02	< 0.02
Cr	< 0.02	< 0.02
Cu	< 0.5	< 0.5
Hg	0.0004	0.0004
Mo	0.5	0.1
Ni	< 0.01	< 0.01
Pb	0.18	0.11
V	< 0.5	< 0.5
Zn	< 0.5	< 0.5
Ra	69*	105*
Th	< 0.1	< 0.1
U	13.31	4.55

†Value in pH units

*Value in picocuries/ℓ

attain zero discharge. This is expected to be accomplished by increased use of recycling and by minor process modifications.

Mill 9401. This operation is located in New Mexico and extracts uranium and vanadium byproducts by alkaline leaching processes. (See Section III.) The mill has no point discharge. The mill incorporates two recycle loops: one involving recarbonization of leach, which leaves all water characteristics relevant to discharges essentially unchanged, and another loop that returns decant water from tailings by means of an ion-exchange column. The IX process recovers uranium that was rejected to tailings and solubilized there; however, this loop also does not improve water quality.

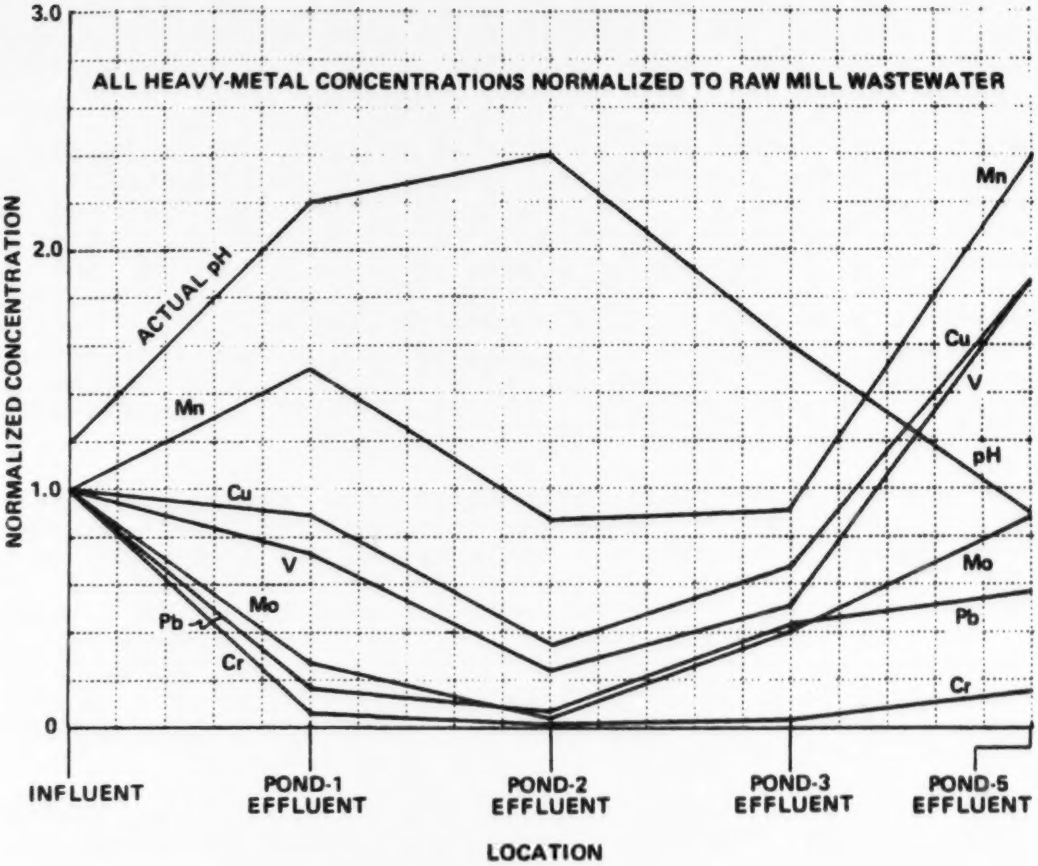
As discussed in Section III, the alkaline-leach process used at this mill involves a purification step that adds sodium and sulfate ions to the water. If water were recycled indefinitely, these ions would increase in the tailing ponds. Evaporation there would eventually permit crystallization of sodium sulfate, and the formation of crystals in other portions of the loop would prevent the use of the recycle liquor, even for such operations as repulping of tailings.

Certain measures, which allow recycling of a significant portion of the flow, must be taken to separate sodium sulfate resulting from the purification process from the other recyclable liquors. A separate, lined evaporation pond would serve this function.

Mill 9402. The mines and mill are located near each other at this operation in New Mexico, and some water from the mines is used in the acid-leach process, while the remainder is discharged. The mill itself has no point discharge.

Like most acid-leach operations, the mill cannot practice recycle from tailing decant liquor (without treatment by reverse osmosis) because high concentrations of solutes interfere with the process of concentrating values. The effect of evaporation on the tailings that are pumped through a sequence of four sequential ponds is illustrated in Figure VII-19. The initial drop is due to chemical precipitation and is followed by a rise in concentration due to a redissolution in acid concentrated by evaporation of water. If vertical seepage or discharge were to result from this operation, neutralization of the acid waste liquors to

Figure VII-19. CHEMICAL CHANGES IN A SEQUENCE OF TAILING IMPOUNDMENTS AT MILL 9402



prevent discharge of innocuous salts and resolubilized heavy metals would be necessary.

Lateral seepage from the first tailing pond is controlled by pumping from a second seepage collection "pond," at the toe of the dam, to safer storage in a third pond, which is at a higher elevation than the first tailing pond. From there, water may be pumped to one of two smaller ponds at even higher elevation. This arrangement of ponds provides protection against failure of any one dam, except for the main tailing dam. Failure of the dams retaining the upper ponds would dump their contents into the larger, lower ponds, rather than into the environment.

Mill 9403. This mill is located in Utah. Mines supplying this operation are completely separated from the mill and were not visited. The mill uses alkaline leach and has extensive byproduct operations. Its discharge to a river is expected to be reduced in volume by a factor of ten or eliminated in late 1975. Complete recycle is technically possible but would require expensive alterations to waste-treatment facilities. Land suitable for construction of a pond large enough to remove waste liquor by evaporation is several kilometers away and is located at an elevation several hundred meters higher.

The present mill treats river water (to reduce hardness), raw wastewaters (to remove suspended and settleable solids), and decant water from the tailing pond (to remove radium by $BaCl_2$ coprecipitation). The water-softening scheme is not properly an effluent treatment, but it illustrates a large-scale technique for reducing calcium and magnesium, by reducing calcium carbonate content from approximately 500 mg/l to 35 mg/l. Table VII-48 shows the effect of tailing-pond and coprecipitation treatments on effluent characteristics.

Mill 9404. This mill, located in New Mexico, is approximately 100 km (60 miles) from the mine that furnishes ore.

The mill uses acid leaching, and recycle is not practical. A tailing pond, 3 kilometers (2 miles) from the mill, evaporates wastewater and concentrates the solutes. The tailing area covers a somewhat porous stratum. For this reason, a deep well was drilled to a depth of 770 meters (2,530 feet) into porous strata containing water unfit for other use, and decant wastewater from the pond is occasionally injected into this well, following filtering to

TABLE VII-48. CHEMICAL COMPOSITIONS OF RAW AND TREATED WASTEWATERS AND EFFLUENT WASTE LOADING AT MILL 9403 (SETTLING AND $BaCl_2$ COPRECIPITATION)

PARAMETER	CONCENTRATION (mg/ℓ)		EFFLUENT WASTE LOAD			
	RAW WASTEWATER	TREATED EFFLUENT	kg/day	lb/day	kg/metric ton of concentrate	lb/short ton of concentrate
pH	9[*]	9[*]	–	–	–	–
TSS	111,000	31	161	354	120	240
COD	27.8	71.4	370	814	270	540
TOC	< 1	20	100	220	74	148
As	1.4	2.8	15	33	10	20
Cd	0.04	< 0.02	< 0.1	0.22	–	–
Cr	< 0.02	< 0.02	< 0.1	0.22	–	–
Cu	1.1	< 0.5	< 2.6	< 5.7	–	–
Hg	0.0016	0.0002	0.001	0.0022	0.0007	0.0014
Mo	0.25	3.3	17	37	12	24
Ni	0.52	< 0.01	< 0.05	< 0.11	–	–
Pb	0.69	0.13	0.67	1.47	0.48	0.96
V	< 0.5	7.4	38	84	30	60
Ra	111[†]	4.09[†]	21.2[**]	–	15.8[††]	14.4[***]
Th	–	< 0.1	< 0.5	<1.1	–	–
U	3.9	2.5	13	29	10	21

[*] Value in pH units

[†] Value in picocuries/ℓ

[**] Value in microcuries/day

[††] Value in microcuries/metric ton

[***] Value in microcuries/short ton

remove suspended solids that might plug the well. There is no point discharge at this mill.

Mill 9405. This mill is located in western Colorado within a few miles of many small mines yielding uranium and vanadium ores. The mill uses acid leaching and produces more vanadium than uranium, with vanadium concentrated by solvent exchange. Waste liquors from the vanadium process are evaporated in ponds as are some liquid wastes from uranium refining. Effluents from yellow cake (uranium) precipitation and washing are combined with hillside runoff and treated by barium chloride coprecipitation which reduces Ra 226 concentrations from a level of about 40 picocuries per liter (pC/l) to 1 to 3 pC/l using 0.06 to 0.09 gram $BaCl_2$ per liter in the presence of 5000 mg/l of sulfate ion.

Metal Ores, Not Elsewhere Classified

This group contains ore mining and dressing operations which vary considerably in their size, methods of mining and beneficiation, and location. Relatively few operations are represented in this diverse group, with primary production for antimony, beryllium, platinum, and rare-earth ores represented by one mine and mill each. Tin and zirconium ores are obtained as byproducts, while antimony is also obtained as a byproduct of both silver mining and milling and lead and zinc smelting.

Antimony Ores

There currently exists only one operation (mine/mill 9901) which is mining and milling ore primarily for its antimony content. Mill 9901 discharges tailings from its flotation circuit to a tailing pond and achieves zero discharge by impoundment of tailings in this pond. The operators of this mill also indicate that recycling of tailing-pond process water would not be expected to pose any problems, should recycling become desirable at this mill. However, if this water were to be recycled, additional settling treatment would be necessary to reduce its slime content. Therefore, the impoundment area would require either expansion or redesign to facilitate a recycle system.

No effluents are currently being discharged to the surface from mine 9901. However, this operation has been active for only a few (three to five) years; as the mine is developed more extensively, a discharge may result from the influx of ground water. If discharged, the mine wastewater may potentially contain suspended solids and solubilized metals, which will require treatment prior to final discharge of the effluent. Treatment technologies potentially available for application at this mine are chemical precipitation and flocculation methods and use of settling basins, previously discussed.

Chemical precipitation of metal hydroxides by lime addition will successfully remove most of the heavy metals (i.e., arsenic and zinc) present in this ore body. Lime will also create the alkaline conditions necessary for the successful removal of antimony by sulfide precipitation.

Beryllium Ores

Only one operation in the beryllium mining and milling industry is known to use water in a milling process. The limited amount of beryl mined domestically is, for the most part, concentrated by crude hand-cobbing methods. However, bertrandite, mined from an open pit, is processed at mill 9902 by a sulfuric acid leach process. This mill is achieving zero discharge by impoundment of the mill tailings in a tailing pond. Water is removed from the pond by natural evaporation and possible percolation into the subsurface. No discharge exists from the open-pit mine at this time.

Platinum-Group Metals

The bulk of production of the platinum-group metals results from recovery as byproducts from copper ore during refining operations. These metals are also being recovered by an operation (mine/mill 9904) which seasonally mines a placer deposit in Alaska. This placer, located alongside a major river, is mined by a dredge, floated on a impoundment constructed over the deposit. The heavy minerals are concentrated by gravity-separation methods; therefore, waste loading of the process water includes primarily suspended solids. These process wastes are discharged to the dredge pond, where some settling of the solids occurs. The suspended-solid content of the pond water is further reduced as it filters through a sand barrier prior to final discharge.

The relatively unsophisticated methods described above are typical of the best existing treatment at precious-metal placer operations. As such, this treatment is designed to reduce suspended-solid loadings of final discharges. Since recycle is usually not practicable at a placer operation of this type, use of the treatment described is necessary.

Therefore, efficient treatment can be maximized by optimizing conditions for settling and/or filtration of the process wastes. Long-range control of solids should take the location of the treatment facilities into consideration. These facilities should, when possible, be located at a distance from a stream, which would afford protection from seasonally high waters.

Table VII-49 presents the chemical composition and treated waste load for mine/mill 9904.

Rare-Earth Ores

Currently, only one operation mines a lode deposit for its rare-earth mineral content. This operation (mine 9903) mines bastnaesite from an open pit and concentrates the ore in a flotation circuit. The flotation concentrate is further upgraded in a leach circuit before final processing in a solvent-extraction plant. Presently, the flotation tailings are discharged to a tailing pond, and the clarified pond water is recycled back into the flotation circuit. Process wastes from the leach circuit are separately discharged to an evaporation pond. The efficiency of tailing-pond treatment of the water to be recycled is presented in Table VII-50.

The rare-earth mineral monazite is recovered primarily as a byproduct of titanium operations. Treatment technology employed at these operations is discussed under Titanium in this section.

Segregation of Waste Streams. Because mine/mill 9903 is located in an arid region, water is a scarce commodity at this site. It is primarily for this reason that water is recycled from the tailing pond back to the flotation circuit. The leach-circuit wastes are not combined with the water to be recycled, as this waste contains very high dissolved-solid concentrations, which would undoubtedly cause interference in the flotation circuit. At this mill, the waste streams have been segregated, then, to facilitate recycle.

Tin Ores

Tin is obtained as a byproduct of molybdenum mining and milling at one location in the United States. No separate discharges result from tin mining or processing.

TABLE VII-49. CHEMICAL COMPOSITION OF TREATED EFFLUENT AND WASTE LOAD FROM MINE/MILL 9904 (PLATINUM)

PARAMETER	CONCENTRATION (mg/ℓ) IN WASTEWATER	TREATED WASTE LOAD per unit of ore milled	
		kg/1000 metric tons	lb/1000 short tons
COD	7.6	0.11	0.22
TSS	30	0.43	0.86
Fe	0.17	0.002	0.004
Pb	0.01	0.0001	0.0002
Zn	0.03	0.0004	0.0008
Fluoride	0.95	0.01	0.02

TABLE VII-50. CHEMICAL COMPOSITIONS OF RAW WASTEWATER AND TREATED RECYCLE WATER AT MILL 9903 (NO DISCHARGE)

PARAMETER	CONCENTRATION (mg/ℓ)	
	RAW WASTEWATER	TREATED RECYCLE WATER
pH	9.02*	7.58*
TSS	360,000	17,300
TDS	14,476	9,576
TOC	3,100	1,400
Cr	0.35	0.03
Total Mn	0.5	4.5
V	< 0.3	< 0.3
Y	–	0.014
La	–	1.32
Ce	–	2.75
Pr	–	0.27
Nd	–	0.51
Sm	–	41
Eu	–	< 0.001
Gd	–	0.006
Th	–	< 0.001
Fluoride	365	55

*Value in pH units

Titanium Ores

Titanium ores mined and milled in the United States occur in two modes: as a hard rock deposit and as placer or heavy-sand deposits of ilmenite, rutile, and leucoxene. The methods of mining and beneficiation of both types of deposits are described in detail in Section III. The treatment and control technologies employed at exemplary operations in this ore category are described below.

Mine/Mill 9905. In the U.S., one operation is presently mining a lode deposit for titanium minerals (primarily, ilmenite). At this operation, ore mined from an open-pit mine is crushed and floated to concentrate the ilmenite. Prior to flotation, magnetite associated with the ilmenite is magnetically separated from the ore.

Process wastes, largely from the flotation circuit, are discharged to a formerly used open-pit quarry, which serves as a tailing pond. Clarified overflow from this pit is recycled back into the mill circuit. Tailing-pond treatment-efficiency data are presented in Table VII-51. No chemicals are added for treatment purposes, although the process water has an alkaline pH.

Although this mill employs a recycle system, rain and runoff which collect in the recycle system occasionally result in a seasonal discharge. Diversion ditching is not presently used at this mill. If diversion ditching or other systems were installed to prevent excess water from collecting, a seasonal discharge might not occur at mill 9905.

Water is currently discharged from open-pit mine 9905. Prior to final discharge, this water is retained for settling for a short time in a small pond. Improved treatment of this mine water could be attained by increased retention time in a pond, and by treatment with lime or other precipitating agent to ensure optimum metal and fluoride removal.

Mine/Mills 9906 and 9907. These operations recover titanium minerals (ilmenite and rutile) and the zirconium mineral zircon from sand placers. Similar operations also recover the rare-earth mineral monazite.

As these placer deposits are located inland, the typical practice is to construct a pond over the ore body and to mine the placer by dredging. The heavy-mineral sands are upgraded by gravity methods in a flotation mill, and the heavy minerals in the bulk concentrate are separated and concentrated by electrostatic and magnetic methods in a dry mill.

TABLE VII-51. CHEMICAL COMPOSITIONS OF RAW WASTEWATER AND TREATED RECYCLE WATER AT MILL 9905

PARAMETER	CONCENTRATION (mg/ℓ)	
	RAW WASTEWATER	TREATED RECYCLE WATER
Conductivity	650*	490*
Turbidity (JTU)	2.2	0.56
TSS	26,300	2
TDS	518	526
TOC	9.0	12.5
Oil and Grease	2.0	2.0
As	< 0.01	0.01
Cd	< 0.002	< 0.002
Cr	0.58	0.02
Cu	0.43	< 0.03
Total Fe	630	< 0.02
Pb	< 0.05	< 0.05
Total Mn	5.9	0.3
Hg	0.004	< 0.0002
Ni	1.19	< 0.01
V	2.0	< 0.5
Ti	2.08	< 0.2
Zn	7.6	< 0.002
Nitrate	0.68	0.50

*Value in micromhos/cm

Process wastes emanating from the wet mill are discharged to the dredge pond. However, as discussed in Section V, the primary waste constituents of the dredge-pond effluents are the colloidal organic materials, of high coloring capacity, present in the ore body. These materials are flocculated by reducing the pH to 3.5 with sulfuric acid. The water then flows through a large pond system, where the coagulated sludge settles. The clarified overflow from this system is neutralized with lime prior to final discharge to the receiving stream. Both acid and lime are fed by automatically controlled equipment. Reagents are added to the waste stream in flumes designed to create turbulent mixing. The treatment efficiency of this system is presented in Tables VII-52 and VII-53 for operations 9906 and 9907, respectively. Waste-load reduction data are presented in Tables VII-54 and VII-55.

Potential Control Technology at Sand Placer Operations. Water used in the wet mill at these placer mines is drawn from the dredge pond; therefore, in this sense, process water is recycled. However, some fresh water is required for use as pump seals, as wash water in the finisher spirals, or in "laminar flows" (gravity-separation devices), and this water is drawn from a well.

A degree of waste-load reduction could be achieved by partial recycle of the treated dredge-pond effluent back to the wet mill for use in the finisher spirals or laminar flows. Treated water would be suitable to replace the fresh water now used Fin the wet mill. The primary reason why this practice is not currently employed is that water can be drawn from wells at less expense than required to recycle treated water.

Zirconium Ores

No primary operations for zirconium ores exist in the United States. Zirconium is obtained as a byproduct of heavy-mineral sand placer operations for titanium. No separate discharge or waste loading can be assigned to this metal.

SUMMARY OF MINE/MILL OPERATIONS EMPLOYING EXEMPLARY WASTEWATER TREATMENT

Tables VII-56 and VII-57 present a summary of information pertaining to mine/mill operations, in all metal-ore categories, which employ exemplary wastewater-treatment technology exclusive of zero discharge. These tables reflect several data sources, including NPDES discharge

TABLE VII-52. CHEMICAL COMPOSITIONS OF RAW AND TREATED WASTEWATERS AT MILL 9906

PARAMETER	CONCENTRATION (mg/ℓ)	
	RAW WASTEWATER	TREATED EFFLUENT††
pH	–	7.7*
Conductivity	125†	280†
Color	51,400**	75**
TDS	1,606	96
TSS	11,000	11
COD	1,337.6	14.4
TOC	972.0	6.8
Oil and Grease	400	1.0
Al	69	2.8
As	0.05	0.01
Cr	0.03	< 0.01
Cu	< 0.03	< 0.03
Total Fe	4.9	0.25
Total Mn	0.036	< 0.01
Hg	–	0.0002
Ti	< 0.2	< 0.2
Zn	0.014	0.017

*Value in pH units

†Value in micromhos/cm

**Value in cobalt units

††Surge pond, diluted

TABLE VII-53. CHEMICAL COMPOSITIONS OF RAW AND TREATED WASTEWATERS AT MILL 9907

PARAMETER	CONCENTRATION (mg/ℓ)	
	RAW WASTEWATER	TREATED EFFLUENT
pH	–	6.4*
Conductivity	40†	255†
Color	16,240**	13**
TDS	370	172
TSS	209	4
COD	361.6	12.8
TOC	321.2	3.8
Oil and Grease	40	1.0
Al	15	1.0
As	0.03	0.01
Cr	< 0.01	< 0.01
Cu	< 0.03	< 0.03
Total Fe	0.93	0.12
Total Mn	<0.01	0.04
Hg	0.0024	0.003
Ti	0.40	< 0.2
Zn	< 0.002	0.025

*Value in pH units

†Value in micromhos/cm

**Value in cobalt units

TABLE VII-54. WASTEWATER COMPOSITION AND TREATED WASTE LOAD WITH ACID FLOCCULATION AND SETTLING AT MILL 9906

PARAMETER	CONCENTRATION (mg/ℓ) IN WASTEWATER	TREATED WASTE LOAD per unit concentrate produced[*]	
		kg/1000 metric tons	lb/1000 short tons
pH	7.7[†]	–	–
TDS	96	4,130	8,260
TSS	11	473	946
COD	14.4	620	1,240
TOC	6.8	290	580
Oil and Grease	1.0	43	86
Al	2.8	120	240
As	0.01	0.43	0.86
Cr	< 0.01	< 0.43	< 0.86
Cu	< 0.03	< 1.3	< 2.6
Total Fe	0.25	11	22
Total Mn	< 0.01	< 0.43	< 0.86
Hg	0.0002	0.009	0.018
Ti	< 0.2	< 8.6	< 17.2
Zn	0.017	0.73	1.46

[*] Total amount of ore milled unavailable

[†] Value in pH units

TABLE VII-55. WASTEWATER COMPOSITION AND TREATED WASTE LOAD WITH ACID FLOCCULATION AND SETTLING AT MILL 9907

PARAMETER	CONCENTRATION (mg/ℓ) IN WASTEWATER	TREATED WASTE LOAD per unit concentrate produced*	
		kg/1000 metric tons	lb/1000 short tons
pH	6.4†	–	–
TDS	172	7,050	14,100
TSS	4	164	328
COD	12.8	520	1,040
TOC	3.8	150	300
Oil and Grease	1.0	41	82
Al	1.0	41	82
As	0.01	0.41	0.82
Cr	< 0.01	< 0.41	< 0.82
Cu	< 0.03	< 1.2	< 2.4
Total Fe	0.12	4.9	9.8
Total Mn	0.04	1.6	3.2
Hg	0.0003	0.01	0.02
Ti	< 0.2	< 0.82	< 1.6
Zn	0.025	1	2

*Total amount of ore milled unavailable

†Value in pH units

TABLE VII-56. EFFLUENT CONCENTRATIONS ACHIEVED AT MINES EMPLOYING TREATMENT TECHNOLOGY

MINE	PRODUCT	ANNUAL PRODUCTION (metric tons/year*)	WASTEWATER		PARAMETER CONCENTRATION (mg/l)																			
					RAW WASTEWATER										TREATED WASTEWATER									
			TREATMENT METHOD	VOLUME DISCHARGED (m^3/day†)	pH**	TSS	COD	Al	TOTAL Fe	DISSOLVED Fe	TOTAL Ra 226††	DISSOLVED Ra 226††	TOTAL U	Zn	pH**	TSS	COD	Al	TOTAL Fe	DISSOLVED Fe	TOTAL Ra 226††	DISSOLVED Ra 226††	TOTAL U	ZN
1105	Iron Ore	8,519,000 (wet)	Coagulation Settling	22,220	7.9	6	NR	NR	<0.02	<0.02	NR	NR	NR	NR	7.9 (±0.2)	3.2 (±1.1)	NR	NR	NR	0.015	NR	NR	NR	NR
5101	Bauxite Ore	813,000	Lime Pptn Settling	7,165	3.3	15	NR	25	50.9	NR	NR	NR	NR	1.01	6.4	2.6	NR	0.56	0.17	NR	NR	NR	NR	0.06
5102	Bauxite Ore	883,840	Lime Pptn Settling	2,660 (tr) 14,140 (td)	2.8	45	NR	14.8	49	NR	NR	NR	NR	0.24	7.3	5.8	NR	0.41	0.30	NR	NR	NR	NR	<0.02
9408	Uranium Ore	56,820(1)	Lime Pptn Settling, $Fe_2(SO_4)_3$ Pptn $BaCl_2$ Pptn	1,140	8.15	31	10	NR	NR	NR	39.8 [±0.4]	35.1 [±0.3]	2.5	0.026	8.5	14	10	NR	NR	NR	1.6 [±0.1]	0.6 [±0.1]	3.0	0.014

* To convert to short tons/year, multiply value shown by 1.10231
† To convert to gal/day, multiply value shown by 264.173
** Value in pH units
†† Value in picocuries/l
( ) (Parentheses) enclosing data indicate that value shown is standard deviation calculated from company data (where sufficient data were available)
[ ] [Brackets] enclosing data indicate that value shown is analytical accuracy
NR indicates that parameter is not regulated under BPCTCA applicable to the particular mining operation
Pptn indicates precipitation
tr indicates volume treated
td indicates volume of total drainage
(1) Assumes a 250-day year

TABLE VII-57. EFFLUENT CONCENTRATIONS ACHIEVED AT MILLS EMPLOYING TREATMENT TECHNOLOGY

MILL	PRODUCT	ANNUAL PRODUCTION (metric tons/year*)	CONCENTRATION PROCESS	WASTEWATER		PARAMETER CONCENTRATION (mg/l)																					
						RAW WASTEWATER											TREATED WASTEWATER										
				TREATMENT METHOD	VOLUME DISCHARGED (m^3/day†)	pH**	TSS	COD	As	Cu	DISSOLVED Fe	Pb	TOTAL Ra 226††	DISSOLVED Ra 226††	Zn	CN	pH**	TSS	COD	As	Cu	DISSOLVED Fe	Pb	TOTAL Ra 226††	DISSOLVED Ra 226††	Zn	CN
						COPPER, LEAD/ZINC, AND SILVER ORES																					
2120	Cu Concentrate	296,000	Flotation	Lime Pptn Settling	105,980	11.1	353,000	NR	NR	400	NR	21	NR	NR	310	—	—	8 (±3)	NR	NR	0.04 (±0.02)	NR	<0.01 (±0)	NR	NR	0.10 (±0.07)	—
2121	Cu Concentrate	223,318	Flotation	Lime Pptn Settling	97,779	9.3	115,000	↓	↓	152	↓	<0.1	↓	↓	10.5	0.03	9.1	17	↓	↓	0.05	↓	0.01	↓	↓	0.06	—
3101	Pb Concentrate Zn Concentrate	203,970 105,688	Flotation	Lime Pptn Settling	3,840	11.2		↓	↓	396	↓	105	↓	↓	1,667	—	8.3 (±1.2)	—	↓	↓	0.022 (±0.011)	↓	0.021 (±0.016)	↓	↓	0.11 (±0.07)	—
3103	Pb Concentrate Zn/Cu Concentrate	79,907 17,142	Flotation	Settling Alkaline pH	9,500	7.9	—	↓	↓		↓	—	↓	↓	—	<0.01	7.8 (±0.3)	2.3 (±2.3)	↓	↓	0.01 (±0.01)	↓	0.04 (±0.01)	↓	↓	0.09 (±0.06)	<0.01
3104	Zn Concentrate Pb Concentrate	120,704 4,418	Flotation	Settling Alkaline pH Recycling	8,426	—	347,000	↓	↓	—	↓	—	↓	↓	—	—	8.1 (±1.2)	7.3 (±5.1)	↓	↓	0.022 (±0.015)	↓	0.073 (±0.036)	↓	↓	0.13 (±0.12)	—
3105	Zn Concentrate	54,420	Flotation	Settling Alkaline pH	5,450	—	190,000	↓	↓	—	↓	—	↓	↓	—	—	—	8	↓	↓	0.04	↓	<0.03	↓	↓	0.10	—
3106	Pb Concentrate Zn Concentrate	23,970 885	Flotation	Flocculation Settling Alkaline pH	4,731	7.9	125,000	↓	↓	9.0	↓	560	↓	↓	182		8.0 (±0.4)	26 (±17)	↓	↓	0.010 (±0.01)	↓	0.25 (±0.12)	↓	↓	0.12 (±0.08)	—
3108	Zn Concentrate	18,221	Flotation	Settling Alkaline pH	1,136			↓	↓		↓		↓	↓	—	—	7.4	8.9	↓	↓	0.02	↓	0.04	↓	↓	0.14	—
4401	Cu/Ag Concentrate	4,570	Flotation	Settling Alkaline pH Partial Recycling	1,140		550,000	↓	↓	0.25	↓	<0.1	↓	↓	0.033	0.05	7.0	3.9	↓	↓	0.04	↓	0.022	↓	↓	0.033	0.025
6403	Cu/Ag/Sb Concentrate (Chalcopyrite Pyrite and Tetrahedrite)	8,280	Flotation	Settling Alkaline pH	1,132	—	203,000	↓	↓	0.01	↓	<0.1	↓	↓	0.11	—	9.1	25	↓	↓	<0.02	↓	0.017	↓	↓	0.031	—
						IRON ORE																					
1107	Fe Concentrate	2,052,930	Flotation	Settling	13,440	7.5	26	NR	NR	NR	0.07	NR	NR	NR	NR	NR	7.5 (±0.2)	3 (±4)	NR	NR	NR	0.05 (±0.05)	NR	NR	NR	NR	NR
1108	Fe Concentrate	2,718,130	Flotation	Coagulation Settling	45,475	8.1	35,000	↓	↓	↓	0.15	↓	↓	↓	↓	↓	8.0	1.1	↓	↓	↓	0.05	↓	↓	↓	↓	↓
1109	Fe Concentrate	3,598,040	Flotation Magnetic Separation	Settling	22,330	8.5	—	↓	↓	↓	0.05	↓	↓	↓	↓	↓	7.7 (±0.3)	3 (±2)	↓	↓	↓	0.6 (±0.22)	↓	↓	↓	↓	↓
						FERROALLOY ORE																					
6101	MoS_2 Concentrate	8,360	Flotation	Coagulation Settling	22,000	—	180,000	135	<0.01	51	NR	NR	NR	NR	78.9	0.02	7.8	1.8	NR	<0.02	0.022	NR	NR	NR	NR	0.06	<0.01
						URANIUM/VANADIUM ORE																					
9403	U Oxide Concentrate Cu Concentrate	327 150	Acid Leaching RIP Ion Exchange	Settling Coagulation $BaCl_2$ Pptn	6,060	9	92,000	27.8	1.4	NR	NR	NR	111 (±11)	—	0.395	NR	9.4	20	71.4	0.8	NR	NR	NR	4.00 (±0.41)	3.0	<0.005	NR
9405	U Oxide (~85% U_3O_8) V Product Liquor (~10% V_2O_5)	527 22,730	Solvent Extraction Ion Exchange Pptn	$BaCl_2$ Pptn Settling	1,250	—	184	48	0.034	NR	NR	NR	16.1 (±1.6)	—	0.26	NR	7.3	20	22	<0.003	NR	NR	NR	0.2 (±0.1)	—	0.15	NR

* To convert to short tons/year, multiply value shown by 1.10231
† To convert to gal/day, multiply value shown by 264.173
** Value in pH units
†† Value in picocuries/l
( ) (Parentheses) enclosing data indicate that value shown is standard deviation calculated from company data (where sufficient data were available)
[ ] [Brackets] enclosing data indicate that value shown is analytical accuracy
NR indicates that parameter is not regulated under BPCTCA applicable to the particular mining operation
Pptn indicates precipitation

permits, industry monitoring data, and results of analysis of samples collected by the contractor during site visits. Treated waste concentrations presented in the tables are numerical averages, based, in most instances, on the most recent and most comprehensive monitoring data supplied by members of the industry. Concentrations for those treated-waste parameters not monitored at a particular operation were derived from contractor sample analysis. In addition, raw-waste concentrations were also derived--primarily, from contractor sampling data. In all instances, metal parameter concentrations are total metal values unless specifically identified otherwise. For those mines and mills where nine or more data points were available, standard deviations were calculated as a measure of central tendency. Most annual production figures for the exemplary facilities are based on actual 1973 production, although a few figures reflect more recent production schedules.

The information summarized in these tables provided much of the data base used for recommending the BPCTCA and BATEA effluent limitations for those categories not achieving, or recommended to achieve, zero discharge. These limitations are identified in Sections IX and X of this document.

SECTION VIII

COST, ENERGY, AND NONWATER-QUALITY ASPECTS

INTRODUCTION

The costs of implementation of the best practicable control technology currently available, the best available technology economically achievable and new source performance standards for the ore mining and dressing industry, as required by Section 304 of the Federal Water Pollution Control Act Amendments of 1972 (PL92-500), are summarized in this section; the costs of implementation of any other Federal, State or local regulations are not considered.

Included in this section are capital and annual operating costs which will be incurred by representative operations in each of the industrial subcategories within the ore mining and dressing point source category. Also included in this section where applicable, are the cost of diversion ditching required for control of runoff specifically for pollution control. These costs represent incremental costs to attain specified effluent treatment levels. For example, if the prevailing current practice encompasses use of tailing ponds, the capital and operating costs associated with such ponds are not included. The costs of any additional treatment facility or activity necessary to meet the prescribed standards, however, are included.

Separate capital and annual costs for BPCTCA and BATEA, and to achieve the New Source Performance Standards are tabulated for typical or representative plants in each industrial subcategory. Again, these are always expressed as incremental costs. These costs are then combined in a summary table to show the total costs incurred to attain the specified effluent levels. All costs are expressed in 1972 dollars. The Marshall and Stevens Equipment Cost Index for mining and milling is used where cost adjustments are required.

A summary of the costing methodology employed is presented in the section which follows. A detailed description of the cost categories, factors, relationships, data sources, and assumptions utilized in computation of the industry costs is contained in Supplement B. The selected approach entailed the derivation and validation of costs for the various facilities, activities, and materials which, in combination, form the specified treatment processes.

Where applicable and practical, the costs are developed as a function of variables which are generally known for specific facility operations. Supplement B is organized to facilitate the computation of treatment costs for other specified plant operations.

SUMMARY OF METHODS USED

Capital Costs

Capital costs include all costs incurred for the construction, procurement, and installation of required treatment facilities and equipment.

The major facility and equipment categories used to compute capital costs are:

- Impoundments
  - Settling Ponds/Lagoons
  - Tailing Ponds
    - Tailing-Pond Distribution System

- Treatment Processes/Facilities/Equipment
  - Clarifiers/Thickeners
  - Lime Neutralization and Precipitation
    - Hydrated-Lime System
    - Pebbled-Lime System
  - Coagulation/Flocculation (including Ferric Sulfate Treatment)
  - Sulfide-Precipitation Treatment
  - Ion Exchange
  - Aeration
  - Barium Chloride Coprecipitation
  - Ammonia Stripping
  - Recarbonation/Sulfur Dioxide Addition

- Transport Systems
  - Pipes
  - Pumps
- Land
- Other Costs
  - Contingency
  - Contractor Fee

The cost of impoundment is computed as a function of the volume contained, total depth, and dike dimensions. Large variations in costs are encountered for the construction of an impoundment of given size. A major factor is the local topography. For example, very little dike construction may be necessary where advantage is taken of an existing ground depression. In other areas, dikes may have to be constructed along the entire perimeter. In estimating impoundment costs for typical plants, it has been assumed that dikes must be constructed around the entire perimeter. Detailed data are presented in Supplement B, however, which permit estimation of costs for specific lagoon and dike designs. The impoundments have been sized to contain or treat, as applicable, the estimated runoff from a 1 in 10-year, 24-hour storm and a 1 in 25-year, 24-hour storm.

It is assumed that cyclones are used at tailing ponds to separate solids from the waste streams.

Thickener and clarifier costs are based on vendor quotations. Costs are determined as a function of capacity.

Treatment costs vary with the characteristics and magnitude of the waste streams. Two types of lime neutralization/precipitation facilities are considered. One uses hydrated lime, introduced as a slurry; the other, pebbled lime, stored dry. The first is practical for operations characterized by flows of less than 18,925 cubic meters (5,000,000 gallons) per day. The second is generally used to treat waste streams of higher volume.

The major components of the hydrated-lime system are tanks, a slurry mixer and feeder with associated instrumentation, pumps, and a building to house the latter two components. Lime storage consists of a 15- to 30-day supply. Treatment facility costs are computed for application of 0.45 and 0.90 kg of lime per 3,785 liters (1 and 2 lb/1000 gal) of effluent flow.

The pebbled-lime system consists of storage silo(s), lime feeders and slakers, mixing tanks, and pumps. Storage silos are designed to accommodate a 15-day supply of lime. Lime feeders and slakers with feed rates of 455 to 1,818 kg (1,000 to 4,000 lb) per hour are used, together with mixing tanks of sufficient size for 15-minute retention. Costs are developed for treatment systems designed to add 0.9 or 1.4 kg of lime per 3,785 l (3.785 cubic meters) (equivalent to 2 and 3 lb/1,000 gal) of wastewater.

In some instances, slightly larger applications of lime than previously noted are necessary where either hydrated- or pebbled-lime facilities are used. No changes in facilities are made in these cases. Rather, it is assumed that the lime storage facilities are resupplied more frequently. The increased application of lime thus is reflected only in increased operating costs.

Many variations of coagulation and flocculation are possible. One basic system is considered in this study. It consists of a mixing tank(s), two holding tanks, and two positive displacement pumps. The flocculant is mixed to provide a 0.5-percent solution. The mixture is then transferred to a holding tank, where the solution is diluted to 0.1 percent. One of the holding tanks is used to feed the solution into the waste stream while a new batch of solution is made up in the other. The pumps are used to transfer the solution from the mixing tank to the holding tank and to meter the solution into the waste stream.

Ferric sulfate treatment is essentially similar to coagulation/ flocculation. A three percent solution is mixed directly in two holding tanks and metered into the waste stream. Each tank holds a one-day supply of solution. The need for the mixing tank and one pump is eliminated.

Coagulation/flocculation and ferric sulfate systems are tailored to individual plant requirements, as shown in Supplement B. An important aspect to be noted here is that there are tradeoffs between equipment sizes and the number of batches of solution mixed daily.

The cost of installing a sodium sulfide treatment system generally is very low. In many instances, this system consists of a 208-liter (55-gallon) drum, from which the sulfide solution trickles into the waste stream. The amount needed depends on the characteristics of the waste stream; generally, it is of the order of 1 to 2 mg/l (1 to 2 ppm).

The cost of an ion-exchange unit is a function of the amount of resin needed, which, in turn, depends on the daily flow, the characteristics of the wastewater [illegible] specific standard to be achieved. The a[illegible] is determined for each plant where this treatment is employed. The ion-exchange unit costs include purchase costs of the main unit, and ancillary equipment, as well as installation costs.

Two applications of aeration are considered in the study: one for mixing, the other for oxidation. The former is designed to raise the DO level in the wastewater. Its cost is determined on the basis of the volume of water to be agitated. The latter application consists of the chemical addition of oxygen, where the amount of oxygen required is a function of chemical change to be achieved. The cost in this case is computed from the amount of oxygen which must be added to the water.

Barium chloride coprecipitation treatment costs are based on industry sources. The original data provided information for operation rated at a 5,670 m^3 (1,500,000 galons) per day. The cost of reagents are not included as part of the capital cost. They are included however, under operating cost.

The main components of a ammonia stripper are a plastic mixing tank containing caustic soda, a metering pump, and a packed column. This treatment is used in only one instance. The amount of wastewater treated is 530 m^3 (140,000 gallons) per day.

Both recarbonation and sulfur dioxide addition utilize a holding tank sized for five minutes of retention. Carbon dioxide or sulfur dioxide is bubbled through the wastewater while it is contained in the holding tank.

Piping and pump requirements depend on the average flow rates, the characteristics of the waste stream, and the distance over which the waste stream must be transported. Pipe and pump sizes and costs for waste streams which contain a significant amount of solids are based on a flow rate of 1 m (3.3 ft) per second and on the use of slurry pumps. Wastewater which carries relatively little solid material is assumed to be pumped at a rate of 2 m (6.6 ft) per second utilizing water pumps. The cost of a standby pump is included in all cases.

All facilities are assumed to be located on rural land. The cost used is $1,755 per hectare ($730/acre).

Contingency and contractor fees are included as 13 percent of the capital costs.

Annual Costs

The cost categories included are:

Annual capital recovery
Facility repair and maintenance

Equipment repair and maintenance
Operating personnel
Material
Energy (Power)
Taxes
Insurance

Annual capital recovery, as defined for this study, includes the cost of both capital and the depreciation. The cost of capital is computed at 8 percent. The assumed useful lives of facilities and equipment are 20 and 10 years, respectively.

Annual capital recovery costs are computed as follows.

$$C\underline{A} = B \, \frac{(r)\ (1 + r)\exp n}{((1 + r)\exp n) - 1}$$

where

B = Initial cost
r = True annual interest rate
n = Useful life in years

Annual land cost is also included in the capital recovery cost. This cost is computed as an opportunity cost at an annual rate of 10 percent.

Facility repairs and maintenance are included as 3 percent of initial capital cost, excluding contingency and fee. The rate applied to equipment is 5 percent of initial installed cost per year. This is an average cost applicable to mining and milling equipment.

One exception to the above rates is the maintenance and repair of tailing ponds. Extensive effort is required for periodically raising the distribution pipes, moving the cyclones, and reshaping the upper portions of the dike(s). The annual cost is estimated at 30 percent of the initial cost of the distribution system (Reference 74).

Operating personnel are assigned for specific tasks which must be performed at the treatment facilities. A cost of $9.00 per hour, which includes fringe benefits, overhead, and supervision, is applied.

Material costs are a function of the type of treatment process employed, the volume of the wastewater which must be treated, its characteristics, and the effluent levels which must be attained. Representative delivered material costs are:

Pebbled Lime	$ 30.80/metric ton	$ 28.00/short ton
Hydrated Lime	38.50/metric ton	35.00/short ton
Sodium Sulfide	0.22/kg	0.10/lb
Flocculant	2.20/kg	1.00/lb
Alum	0.07/kg	0.03/lb
Ion-Exchange (IX) Resins	2,500/cubic meter	70.80/cubic foot
Ferric Sulfate	49.50/metric ton	45.00/short ton
Barium Chloride	805.00/metric ton	730.00/short ton

Energy costs are based on the cost per horsepower-year, computed as follows:

$$Cy = \frac{hp}{E \times P} \times 0.7457 \times hr \times Ckw$$

where

Cy = Cost per year
hp = Total horsepower of motors
E = Efficiency factor
P = Power factor
hr = Annual operating hours
Ckw = Cost per kilowatt hour

Efficiency and power factors are each assumed to be 0.9; the cost per kilowatt hour, $0.012.

The computed cost is increased by 10 percent to account for miscellaneous energy usage.

Annual taxes are computed as 2.5 percent of land costs. Insurance is estimated at 1 percent of capital cost.

The discussions which follow are presented by ore mining/milling category and subcategory. Subcategories in which no operations currently have discharges are not discussed in this section.

WASTE WATER-TREATMENT COSTS FOR IRON-ORE CATEGORY

Iron-Ore Mines

There are 39 major iron-ore-producing mines currently in operation. Ore production from these operations ranges from 65,300 to 40,634,000 metric tons (73,000 to 44,800 [illegible] tons) annually, with mine wastewater ranging from [illegible] 80,000 cubic meters (0 to 21,000,000 gallons) per day.

A typical mine with an annual ore production of 8,460,000 metric tons (9,400,000 short tons) and a wastewater flow of 47,520 cubic meters (12,500,000 gallons) per day was chosen to represent this subcategory.

Two levels of technology are considered. The total cost of each level is shown in Table VIII-1.

Waste Water Treatment Control

Level A: Coagulation/Flocculation, Settling, and Discharge

The mine wastewater is treated with 25 mg/l of alum and 1 mg/l of flocculant for suspended-solid removal. The treated effluent is then retained for two days in a settling pond before discharge. The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Flocculation system -
  1 mixing tank of 1900-liter (500-gallon) capacity
  2 holding mix tanks of 9,500-liter (2,500-gallon) capacity

Piping - Flow @ 1 m (3.3 ft)/sec through 60-cm (2-ft) x 250-meter (820-foot) pipe

Pumps - 2 positive-displacement

Pond - 4-meter (13-foot) dike height
  6-meter (20-foot) top width
  143,000-cubic-meter (37,777,000-gal) capacity

Land - 4.2 hectares (10 acres)

TABLE VIII-1. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE

SUBCATEGORY: Iron-Ore Mines

PLANT SIZE: 8,460,000 **METRIC TONS (**9,400,000 **SHORT TONS) PER YEAR OF** ore mined

PLANT AGE: 7 **YEARS** **PLANT LOCATION:** Mesabi Range

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	192.5	384.6			
ANNUAL CAPITAL RECOVERY	21.1	49.7			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	88.6	241.4			
ANNUAL ENERGY AND POWER COSTS	1.3	15.9			
TOTAL ANNUAL COSTS	111.0	307.0			
COSTS($)/METRIC TON OF PRODUCT*	0.013	0.036			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW† (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	30	20	20			
Dissolved Fe	2.1	1.0	0.5			

*ORE MINED. TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

†HISTORICAL DATA

LEVEL A: COAGULATION/FLOCCULATION, SETTLING, AND DISCHARGE

LEVEL B: LEVEL A PLUS LIME PRECIPITATION

Operating-Cost Assumptions for Level A:

Coagulant - 415.8 metric tons (457.4 short tons)/year

Flocculant - 16.67 metric tons (18.34 short tons)/year

Operating personnel - 5 mixes/day @ 1 hr/mix

Power - 9.7 kW (13 hp)

Capital Investment:

Facilities

Lagoon	$ 122,000
Contingency and contractor's fee	15,860
Total facility cost	$ 137,860

Land	7,350

Equipment

Flocculation/Coagulation unit	14,900
Piping	27,000
Equipment subtotal	41,900
Contingency and contractor's fee	5,445
Total equipment cost	47,345
Total Capital Investment	192,555

Annual Cost:

Amortization

Facility	$ 14,040
Equipment	7,055
Total Amortization	$ 21,095

Operation and Maintenance (O&M)

Land	$ 735
Operating personnel	15,750
Facility repair and maintenance	3,660
Equipment repair and maintenance	2,095
Materials	64,260
Taxes	185
Insurance	1,925
Total O&M costs	$ 88,610

Electricity	1,325
Total Annual Cost	$ 111,030

Level B: Level A plus Lime Precipitation

In addition to level-A technology, the wastewater is treated with 0.9 kg of pebbled lime per 3.785 cubic meters (2 lb/1000 gallons) of wastewater before entering the settling pond. The incremental cost for lime precipitation is shown below.

The capital and operating costs and assumptions for attaining level B are shown below.

Capital-Cost Components and Assumptions for Level B:

Lime precipitation system

Operating-Cost Assumptions for Level B:

Lime - 4,000 metric tons (4,410 short tons)/year
Operating personnel - 2 hr/shift, 6 hr/day
Power - 108 kW (145 hp)

Capital Investment:

Equipment	
Lime precipitation unit	$ 170,000
Contingency and contractor's fee	22,100
Total equipment cost	$ 192,100
Total Capital Investment	$ 192,100

Annual Cost:

Amortization	$ 28,630
Operation and Maintenance (O&M)	
Operating personnel	$ 18,900
Equipment repair and maintenance	8,500
Materials	123,480
Insurance	1,920
Total O&M costs	152,800
Electricity	14,570
Total Annual Cost	$ 196,000

Iron-Ore Mills Employing Chemical and/or Physical Separation

There are 34 iron-ore mills in this subcategory. The amount of ore milled ranges from 364,000 to 6,600,000 metric tons (402,000 to 7,236,000 short tons) annually. The daily mill wastewater ranges from 0 to 22,320 cubic meters (0 to 5,900,000 gallons).

The representative mill operation employing a chemical and/or physical process mills 5,000,000 metric tons (5,550,000 short tons) of ore annually. The wastewater flow is 13,435 cubic meters (3,550,000 gallons) per day.

Two levels of technology are considered for this subcategory. The total cost of each level is shown in Table VIII-2.

Waste Water Treatment Conrol

Level A: Flocculation, Settling, and Discharge

The wastewater is treated with 5 mg/l of flocculant and flows, by gravity, to a settling pond. The retention time is assumed to be two days before discharge.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Assumptions for Level A:

Pond - 3-meter (10-foot) dike height
    6-meter (20-foot) top width
    40,300-cubic-meter (10,646,000-gal) capacity

Flocculation system -
    1 mixing tank @ 1,900-liter (500-gallon) capacity
    2 holding tanks @ 9,500-liter (2,500-gallon) capacity
    2 positive-displacement pumps

Piping - Flow @ 1 meter (3.3 feet)/sec through 32-cm
    (1-ft) x 100-meter (328-foot) pipe

Land - 1.6 hectares (4 acres)

TABLE VIII-2. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Iron-Ore Mills Employing Chemical/Physical Separation

PLANT SIZE: 5,000,000 **METRIC TONS (** 5,500,000 **SHORT TONS) PER YEAR OF** ore milled

PLANT AGE: 17 **YEARS** **PLANT LOCATION:** Michigan

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	65.0	181.0			
ANNUAL CAPITAL RECOVERY	7.5	24.8			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	80.1	139.3			
ANNUAL ENERGY AND POWER COSTS	1.3	13.3			
TOTAL ANNUAL COSTS	88.9	177.4			
COSTS($)/METRIC TON OF PRODUCT*	0.018	0.035			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	200,000	20	20			
Dissolved Fe	1.5	1.0	0.5			

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: FLOCCULATION, SETTLING, AND DISCHARGE
LEVEL B: LEVEL A PLUS LIME PRECIPITATION

Operating-Cost Assumptions for Level A:

Flocculant - 23.45 metric tons (25.8 short tons)/year
Operating personnel - 8 mixes/day @ 1 hour/mix
Power - 9.7 kW (13 hp)

Capital Investment:

Facilities	
Lagoon	$ 34,100
Contingency and contractor's fee	4,435
Total facility cost	$ 38,535
Land	2,800
Equipment	
Flocculation unit	14,900
Piping	6,100
Equipment subtotal	21,000
Contingency and contractor's fee	2,730
Total equipment cost	23,730
Total Capital Investment	$ 65,065

Annual Cost:

Amortization	
Facility	$ 3,925
Equipment	3,535
Total amortization	$ 7,460
Operation and Maintenance (O&M)	
Land	280
Operating personnel	25,200
Facility repair and maintenance	1,025
Equipment repair and maintenance	1,050
Materials	51,805
Taxes	70
Insurance	650
Total O&M costs	80,080
Electricity	1,325
Total Annual Cost	$ 88,865

Level B: Level A plus Lime Precipitation

In addition to level-A technology, the wastewater is treated with 0.9 kg of hydrated lime per 3.785 cubic meters (2 lb/1000 gal) of wastewater before entering the settling pond.

The capital and operating costs and assumptions for attaining this level and this size of operation are shown below.

Capital-Cost Components and Assumptions for Level B:

Lime precipitation system

Operating-Cost Assumptions for Level B:

Lime - 1,127 metric tons (1,240 short tons)/year
Operating personnel - 1 hr/shift, 3 hr/day
Power - 81 kW (108 hp)

Capital Investment:

Equipment

Lime precipitation unit	$ 102,650
Contingency and contractor's fee	13,345
Total equipment cost	$ 115,995
Total Capital Investment	$ 115,995

Annual Cost:

Amortization

Equipment	$ 17,285
Total amortization	$ 17,285

Operation and Maintenance (O&M)

Operating personnel	9,450
Equipment repair and maintenance	5,135
Materials	43,490
Insurance	1,160
Total O&M costs	59,235

Electricity	12,000
Total Annual Cost	$ 88,520

WASTE WATER-TREATMENT COSTS FOR COPPER-ORE CATEGORY

Copper Mines

There are 55 major copper-producing mines currently in operation. Ore production ranges from 130,320 to 34,500,000 metric tons (143,600 to 38,000,000 short tons) annually. Mine wastewater ranges from 0 to 30,522 cubic meters (0 to 8,064,000 gallons) per day.

A representative copper mine produces 16,550,000 metric tons (18,250,000 short tons) a year and has an average daily wastewater flow of 2,725 cubic meters (720,000 gallons).

One level of technology is considered. The total cost for this level is shown in Table VIII-3.

Waste Water Treatment Control

Level A: Lime Precipitation, Settling, Recarbonation, and Discharge

The mine drainage is treated with 0.9 kg of hydrated lime per 3.785 cubic meters (2 lb/1000 gal) to precipitate dissolved metals. The treated effluent is then retained in a settling pond for two days. Recarbonation is required for pH adjustment before discharge.

The capital and operating cost components and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Pond - 3-meter (10-foot) dike height
3-meter (10-foot) top width
8,500-cubic meter (2,245,000-gal) capacity

Lime precipitation system

Recarbonation system -
1 holding tank, 5-minute retention, 9,500-liter (2,510-gallon) capacity
1 ejector

Piping - Flow @ 2 meters (6.6 feet)/sec through 14-cm

TABLE VIII-3. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE

SUBCATEGORY: Copper Mines

PLANT SIZE: 16,550,000 METRIC TONS (18,250,000 SHORT TONS) PER YEAR OF ore mined

PLANT AGE: 19 YEARS PLANT LOCATION: Montana

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	108.1	†			
ANNUAL CAPITAL RECOVERY	15.3	†			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	24.0	†			
ANNUAL ENERGY AND POWER COSTS	5.0	†			
TOTAL ANNUAL COSTS	44.3	†			
COSTS($)/METRIC TON OF PRODUCT*	0.003	†			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	40	20	20			
Pb	0.25	0.2	0.1			
Hg	0.002	0.001	0.001			
Zn	31.3	0.5	0.5			
Cu	5.30	0.05	0.05			

*ORE MINED. TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: LIME PRECIPITATION, SETTLING, RECARBONATION, AND DISCHARGE

LEVEL B: LEVEL A + OPERATING EXPERIENCE AND CLOSER CONTROL OF OPERATING CONDITIONS IN TREATMENT SYSTEM.

† NO ADDITIONAL COSTS INCURRED.

(5.5-in.) x 1000-meter (3,280-foot) pipe

Land - 0.54 hectare (1.33 acres)

Operating-Cost Assumptions for Level A:

Lime - 228.6 metric tons (251.5 short tons)/year

Operating personnel - 1 hr/shift, 3 hr/day

Power - 37 kW (50 hp)

CO_2 - can be reclaimed from milling operations; thus, no additional cost

Capital Investment:

Facilities

Lagoon	$ 12,000
Contingency and contractor's fee	1,560
Total facility cost	$ 13,560

Land	975

Equipment

Lime precipitation unit	45,000
Recarbonation	3,800
Piping	34,000
Equipment subtotal	82,800
Contingency and contractor's fee	10,765
Total equipment cost	93,565
Total Capital Investment	$ 108,100

Annual Cost:

Amortization

Facility	$ 1,380
Equipment	13,945
Total amortization	$ 15,325

Operation and Maintenance (O&M)

Land	$ 100
Operating personnel	9,450
Facility repair and maintenance	360

Equipment repair and maintenance	4,140
Materials	8,820
Taxes	25
Insurance	1,080
Total O&M costs	$ 23,975
Electricity	5,000
Total Annual Cost	$ 44,300

Copper Mills Using Froth Flotation

There are five mills in this subcategory. Ore production ranges from 1,211,000 to 17,714,000 metric tons (1,336,000 to 19,530,000 short tons) each year. The daily wastewater flow ranges from 21,760 to 95,000 cubic meters (5,750,000 to 25,000,000 gallons).

A typical operation that annually mills 8,000,000 metric tons (8,840,000 short tons) with a daily wastewater flow of 95,000 cubic meters (25,000,000 gallons) was chosen to represent this subcategory.

Two levels of technology are considered for this subcategory. The total cost of each level is shown in Table VIII-4.

Waste Water Treatment Control

Level A: Lime Precipitation, Polyelectrolyte Addition, Settling, and Discharge

Approximately 70 percent of the mill effluent is treated with 1.36 kg of pebbled lime per 3.785 cubic meters (3 lb/1000 gal) of wastewater to precipitate heavy metals from acid solution. This is later mixed with the remaining effluent. In addition, polyelectrolytes are added during upset conditions (spring and summer) to increase flocculation. The effluent is retained for two days in a settling pond before discharge. The capital and operating cost components and assumptions for attaining this level are shown below.

TABLE VIII-4. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Copper Mills Using Froth Flotation

PLANT SIZE: 8,000,000 METRIC TONS (8,840,000 SHORT TONS) PER YEAR OF ore milled

PLANT AGE: 20 YEARS PLANT LOCATION: North-Central U.S.

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	523.7	1,921.0			
ANNUAL CAPITAL RECOVERY	64.8	286.3			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	342.2	104.2			
ANNUAL ENERGY AND POWER COSTS	21.5	90.0			
TOTAL ANNUAL COSTS	428.5	480.5			
COSTS($)/METRIC TON OF PRODUCT*	0.054	0.06			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	167,000	20	0			
Cyanide	0.02	0.015	0			
Pb**	0.25	0.2	0			
Zn**	0.58	0.2	0			
Cd***	0.06	0.05	0			
Cu**	2.26	0.05	0			
Hg	0.0071	0.001	0			

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: LIME PRECIPITATION, POLYELECTROLYTE ADDITION, SETTLING, AND DISCHARGE
LEVEL B: TOTAL RECYCLE (ZERO DISCHARGE)

**AVERAGE OF TWO TYPICAL FACILITIES FOR THESE PARAMETERS

***HYPOTHETICAL

Capital-Cost Components and Assumptions for Level A:

Pond - 4-meter (13-foot) dike height
6-meter (20-foot) top width
300,000-cubic-meter (79,252,000-gal) capacity

Lime precipitation system

Polyelectrolyte feed system - data supplied from industry surveys.

Piping - Flow @ 2 meters (6.6 feet)/sec through 84-cm (33-in.) x 100-meter (328-foot) pipe

Land - 11 hectares (27 acres)

Operating-Cost Assumptions for Level A:

Lime - 8,100 metric tons (8,910 short tons)/year

Polyelectrolyte - 45.35 metric tons (50 short tons)/year @ $900/metric ton

Operating personnel - 8 hr/day

Power - 160 kW (215 hp)

Capital Investment:

Facilities	
Lagoon	$ 194,000
Contingency and contractor's fee	25,220
Total facility cost	$ 219,220
Land	19,250
Equipment	
Lime precipitation unit	$ 230,000
Polyelectrolyte feed system	9,000
Piping	13,400
Equipment subtotal	252,400
Contingency and contractor's fee	32,810
Total equipment cost	$ 285,210
Total Capital Investment	$ 523,680

Annual Cost:

Amortization

Facility	$ 22,330
Equipment	42,505
Total amortization	$ 64,835

Operation and Maintenance (O&M)

Land	1,925
Operating personnel	25,200
Facility repair and maintenance	5,820
Equipment repair and maintenance	12,620
Materials	290,900
Taxes	480
Insurance	5,235
Total O&M costs	342,180
Electricity	21,500
Total Annual Cost	$ 428,515

Level B: Total Recycle (Zero Discharge)

Total recycle includes additional pumps and piping for recirculating the impounded water from the tailing pond. The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level B:

Piping - Flow @ 2 meters (6.6 feet)/sec through 84-cm (33-in.) x 10,000-meter (32,800-foot) pipe

Pumps - 9 75-kW (100-hp) plus 9 standbys

Operating-Cost Assumptions for Level B:

Power - 675 kW (900 hp)

Capital Investment:

Equipment

Piping	$1,340,000
Pumps	360,000
Equipment subtotal	1,700,000
Contingency and contractor's fee	221,000
Total equipment cost	$ 1,921,000
Total Capital Investment	$1,921,000

Annual Cost:

Amortization	
Equipment	$ 286,290
Total amortization	$ 286,290
Operation and Maintenance (O&M)	
Equipment repair and maintenance	85,000
Insurance	19,210
Total O&M costs	104,210
Electricity	90,000
Total Annual Cost	$480,500

WASTE WATER-TREATMENT COSTS FOR LEAD- AND ZINC-ORE CATEGORY

Lead/Zinc Mines With No Solubility Potential

There are 12 mines in this subcategory. Ore production ranges from 143,300 to 2,280,000 metric tons (158,000 to 2,514,200 short tons) annually. Mine wastewater flow ranges from 6,810 to 49,200 cubic meters (1,800,000 to 13,000,000 gallons) per day.

A hypothetical mine was selected as the representative for this subcategory. It is assumed to have a wastewater flow of 18,925 cubic meters (5,000,000 gallons) a day and an annual ore production of 630,000 metric tons (700,000 short tons).

One level of technology is considered. The total cost of achieving this level is shown in Table VIII-5.

Waste Water Treatment Control

Level A: Sedimentation Lagoon, Secondary Settling, and Discharge

Since there is no solubilization potential for heavy metals, no precipitation is necessary. However, suspended-solid concentrations present a problem. The recommended technology includes use of two settling ponds: one large pond with a 10-day retention and a smaller polishing pond with a 2-day retention.

TABLE VIII-5. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE

SUBCATEGORY: Lead/Zinc Mines (Mines Exhibiting Low Solubility Potential)

PLANT SIZE: 630,000 METRIC TONS (700,000 SHORT TONS) PER YEAR OF ore mined

PLANT AGE: N/A YEARS PLANT LOCATION: N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	413.6	†			
ANNUAL CAPITAL RECOVERY	46.7	†			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	19.5	†			
ANNUAL ENERGY AND POWER COSTS	8.2	†			
TOTAL ANNUAL COSTS	74.4	†			
COSTS($)/METRIC TON OF PRODUCT*	0.12	†			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	138	20	20			
Cu	0.05	0.05	0.05			
Pb	4.9	0.2	0.1			
Zn	0.7	0.5	0.5			
Hg	0.002	0.001	0.001			

*ORE MINED. TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: SEDIMENTATION LAGOON, SECONDARY SETTLING, AND DISCHARGE

LEVEL B: LEVEL A + OPERATING EXPERIENCE AND CLOSER CONTROL OF OPERATING CONDITIONS IN TREATMENT SYSTEM

† NO ADDITIONAL COSTS INCURRED

Capital and operating cost components and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Pond A - 4-meter (13-foot) dike height
6-meter (20-foot) top width
250,000-cubic-meter (66,043,000-gallon) capacity

Pond B - 3-meter (10-foot) dike height
3-meter (10-foot) top width
50,000-cubic-meter (13,209,000-gal) capacity

Piping - from mine to pond A, 1000 meters (3,280 feet); from pond A to pond B, 500 meters (1,640 feet). Flow @ 2 meters (6.6 feet)/sec through 37.5-cm (14.8-in.) pipe.

Pumps - from mine to pond A - 1 plus standby,
13,140 1(3,469 gal)/minute each

Operating-Cost Assumptions for Level A:

Power - 60 kW (80 hp)

Capital Investment:

Lagoon(s)	$ 225,800
Contingency and contractor's fee	29,355
Total facility cost	$ 255,155
Land	19,425
Equipment	
Piping	105,000
Pumps	18,000
Equipment subtotal	123,000
Contingency and contractor's fee	15,990
Total equipment cost	138,990
Total Capital Investment	$ 413,570

Annual Cost:

Amortization

Facility	$ 25,990
Equipment	20,715

Total amortization	$ 46,705
Operation and Maintenance (O&M)	
Land	1,945
Facility repair and maintenance	6,775
Equipment repair and maintenance	6,150
Taxes	485
Insurance	4,135
Total O&M costs	19,490
Electricity	8,165
Total Annual Cost	74,360

Lead/Zinc Mines With Solubility Potential

There are 16 known mines in this subcategory. Annual ore production ranges from 143,300 to 669,240 metric tons (158,000 to 737,860 short tons). Mine wastewater flow ranges from 950 to 131,050 cubic meters (251,000 to 34,623,500 gallons) per day.

A hypothetical mine was selected as representative for this subcategory. It is assumed to have a wastewater flow of 18,925 cubic meters (5,000,000 gal) per day and an annual ore production of 630,000 metric tons (700,000 short tons).

Two levels of technology are considered. The total cost of achieving these levels is shown in Table VIII-6.

Waste Water Treatment Control

Level A: Lime Precipitation, Settling, and Didscharge

Acid mine wastewater has the potential for solubilization of undesired metals. The technology utilized for this occurrence is lime precipitation and settling. Since the mine drainage is acid, a concentration of 1.36 kg of pebbled lime per 3.785 cubic meters (3 lb/1000 gal) of wastewater is required to raise pH sufficiently high for precipitating metals. The treated water is then retained for a minimum of 10 days before discharge. Pumps are not listed as a separate item, since they are integral parts of the lime

TABLE VIII-6. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE

SUBCATEGORY: Lead/Zinc Mines (Exhibiting High Metals Solubility)

PLANT SIZE: 630,000 **METRIC TONS (** 700,000 **SHORT TONS) PER YEAR OF** ore mined

PLANT AGE: N/A **YEARS** **PLANT LOCATION:** N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	407.3	671.5			
ANNUAL CAPITAL RECOVERY	49.1	88.5			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	115.5	129.8			
ANNUAL ENERGY AND POWER COSTS	10.9	11.9			
TOTAL ANNUAL COSTS	175.5	230.2			
COSTS($)/METRIC TON OF PRODUCT*	0.28	0.37			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	58	20	20			
Cu	0.06	0.05	0.05			
Pb	0.3	0.2	0.1			
Zn	38.0	0.5	0.5			
Hg	0.005	0.001	0.001			

*ORE MINED. TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: LIME PRECIPITATION, SETTLING, AND DISCHARGE

LEVEL B: LEVEL A + OPERATING EXPERIENCE AND CLOSER CONTROL OF OPERATING CONDITIONS IN TREATMENT SYSTEM precipitation unit. Capital and operating cost components and assumptions for attaining this level are shown below.

Pond - 4-meter (13-foot) dike height 6-meter (20-foot) top width 250,000-cubic-meter (66,043,000-gal) capacity

Land - 9 hectares (22 acres)

Lime precipitation system

Piping - Flow @ 2 meters (6.6 feet)/sec through 37.5-cm (14.8-in.) x 1000-meter (3,280-foot) pipe

Operating-Cost Assumptions for Level A:

Lime - 2,380 metric tons (2,625 short tons)/year

Operating personnel - 2 hr/shift, 6 hr/day

Power - 80 kW (107 hp)

Capital Investment

Facilities

Lagoon	$ 174,000
Contingency and contractor's fee	22,620
Total facility cost	$ 196,620

Land	15,750

Equipment

Lime precipitation unit	102,500
Piping	70,000
Equipment subtotal	172,500
Contingency and contractor's fee	22,425
Total equipment cost	194,925
Total Capital Investment	$ 407,295

Annual Cost:

Amortization

Facility	$ 20,025

Equipment	29,050
Total amortization	$ 49,075

Operation and Maintenance (O&M)

Land	$ 1,575
Operating personnel	18,900
Facility repair and maintenance	5,220
Equipment repair and maintenance	8,625
Materials	73,500
Taxes	3,625
Insurance	4,070
Total O&M costs	$ 115,515

Electricity	10,900
Total Annual Cost	$ 175,490

Level B: High-Density Sludge Process

In addition to lime and settling as described for level A, a high-density sludge process has been suggested for enhanced removal of dissolved metals.

This process has been costed as a separate item. The incremental cost for implementing this system is shown below. The total cost for this system must be added to level-A costs, since lagoons and lime precipitation are necessary for the operation of this technology. Capital and operating cost components and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level B:

Clarifier - 8-hr retention, 6,350-cubic-meter (1,680,000-gal) capacity.
Underflow from clarifier is 10% of inflow, and 50% of underflow is discharged to settling pond with overflow; thus, 5% of underflow is recirculated through lime precipitation unit.

Slurry Pump - 660 liters (174 gal)/minute

Pipe - Flow @ 1 meter (3.3 ft)/sec through 12.5-cm (4.9-in.) x 50-meter (164-foot) pipe from clarifier to precipitation unit.

Operating-Cost Assumptions for Level B:

Power - 7.5 kW (10 hp)

Capital Investment:

Equipment

Clarifier	$ 226,800
Piping	1,500
Pumps	5,500
Equipment subtotal	233,800
Contingency and contractor's fee	30,395
Total equipment cost	$ 264,195

Annual Cost:

Amortization

Equipment	39,375
Total amortization	39,375

Operation and Maintenance (O&M)

Equipment repair and maintenance	11,690
Insurance	2,640
Total O&M costs	14,330

Electricity	1,000
Total Annual Cost	$ 54,705

Lead/Zinc Mills

There are 21 known major lead/zinc mills in operation. The amount of ore milled by these operations ranges from 195,840 to 2,520,000 metric tons (215,920 to 2,778,390 short tons) annually. The daily mill wastewater flow ranges from 0 to 15,120 cubic meters (0 to 4,000,000 gallons).

A hypothetical mill was selected as representative for this subcategory. It is assumed to have an annual milling capacity of 630,000 metric tons (700,000 shor tons), with a daily wastewater flow rate of 5,678 cubic meters (1,500,000 gallons).

Two alternative levels of technology are considered for this subcategory. The total cost of each level is shown in Table VIII-7.

Waste Water Treatment/Control

The best practiced technology consists of use of a tailing pond, followed by a secondary settling pond. A minimum 10-day retention time in the tailing pond and a 2-day retention time in the secondary settling pond are recommended. The tailing distribution system consists of piping, around the perimeter of the tailing pond, and cyclones, located at 100-meter (328-foot) intervals along one length of the tailing dam.

Capital and operating cost components and assumptions for attaining level A are shown below.

Capital-Cost Components and Assumptions for Level A:

Tailing pond - 3-meter (10-foot) dike height
3-meter (10-foot) top width
4,245-meter (13,925-ft) perimeter

Settling Pond - 3-meter (10-foot) dike height
3-meter (10-foot) top width
15,000-cubic-meter (3,963,000-gal) capacity

Land - 101 hectares (250 acres)

Distribution system - 4,245 meters (13,924 feet) of
(7.9-in.) pipe
12 cyclones @ $1,800 each

Piping - Flow at 1 meter/sec through 30-cm (1-ft) pipe:
from mill to tailing pond, 1000 meters (3,280 ft);
from tailing pond to lagoon, 500 meters (1,640 ft)

Slurry pumps - 1 plus standby, 3,900 l (1,042-gal)/minute

Operating-Cost Assumptions for Level A:

Tailing-pond distribution system maintenance @ 30% of distribution cost

Power - 18.6 kW (25 hp)

TABLE VIII-7. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Lead/Zinc Mills

PLANT SIZE: 630,000 METRIC TONS (700,000 SHORT TONS) PER YEAR OF ore milled

PLANT AGE: N/A YEARS PLANT LOCATION: N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	1,117.0	1,199.0			
ANNUAL CAPITAL RECOVERY	116.6	128.8			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	124.7	129.1			
ANNUAL ENERGY AND POWER COSTS	2.5	6.5			
TOTAL ANNUAL COSTS	243.8	264.4			
COSTS($)/METRIC TON OF PRODUCT*	0.38	0.42			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	350,000	20	0			
Cyanide	0.03	0.01	0			
Cd **	0.055	0.05	0			
Cu	0.36	0.05	0			
Hg	0.015	0.001	0			
Pb	1.9	0.2	0			
Zn	0.46	0.2	0			

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: TAILING POND, SECONDARY SETTLING, AND DISCHARGE
LEVEL B: TOTAL RECYCLE (ZERO DISCHARGE)

**HYPOTHETICAL

Capital Investment:

Facilities

Tailing pond	$ 420,255
Lagoon	19,940
Facility subtotal	440,195
Contingency and contractor's fee	57,225
Total facility cost	$ 497,420

Land

Land	176,750

Equipment

Distribution system	284,790
Piping	93,000
Pumps	14,000
Equipment subtotal	391,790
Contingency and contractor's fee	50,935
Total equipment cost	442,725
Total Capital Investment	$ 1,116,895

Annual Cost:

Amortization

Facility	$ 50,665
Equipment	65,980
Total amortization	$ 116,645

Operation and Maintenance (O&M)

Land	$ 17,675
Facility repair and maintenance	600
Equipment repair and maintenance	5,350
Tailing pond and distribution maintenance	85,435
Taxes	4,420
Insurance	11,170
Total O&M costs	$ 124,650

Electricity

Electricity	2,500
Total Annual Cost	$ 243,795

Level B: Total Recycle (Zero Discharge)

Total recycle can be attained only after impoundment systems as described for level A have been constructed. Thus, the costs cited for level B are the incremental costs for implementing total recycle. The equipment includes decant pumps and piping. Costs for implementing total recycle are shown in Table VIII-7.

Capital-Cost Components and Assumptions for Level B

Decant Pumps - water pumps - 3,900 l (1,042 gal)/minute, 1 plus standby

Piping - Flow @ 2 meters (3.3 feet)/sec through 21-cm (8.3-in.) pipe, 1,500 meters (4,920 feet) long

Operating-Cost Assumptions for Level B:

Power - 30 kW (40 hp)

Capital Investment:

Equipment

Piping	$ 64,500
Pumps	8,000
Equipment subtotal	72,500
Contingency and contractor's fee	9,425
Total equipment cost	$ 81,925

Annual Cost:

Amortization

Equipment	12,210
Total amortization	12,210

Operation and Maintenance (O&M)

Equipment repair and maintenance	3,625
Insurance	820
Total O&M costs	4,445
Electricity	4,000
Total Annual Cost	$ 20,655

WASTE WATER TREATMENT COSTS FOR GOLD ORE CATEGORY

Gold Mines (Alone)

Three known mines operating alone without discharge to mill treatment facilities exist in this subcategory, only two of which are discharging. The range of ore mined is 163,000 to 478,000 metric tons (180,000 to 527,000 short tons) annually. The average daily discharge for these operations is 3,785 cubic meters (1,000,000 gallons).

A hypothetical mine with an annual ore production of 320,000 metric tons (353,000 short tons) and with a discharge of 3,785 cubic meters (1,000,000 gallons) per day was chosen to represent this subcategory.

Two levels of technology are considered. The incremental costs for the representative gold mine to attain levels A and B are shown in Table VIII-8.

Waste Water Treatment/Control

Level A: Sedimentation (Settling Pond)

Level A consists of a sedimentation pond with a one-day retention. It is assumed that mine dewatering pumps already have been installed.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Sedimentation pond - dike height of 3 m (10 ft)
top width of 3 m (10 ft)
capacity of 5,700 cubic meters (1,506,000 gal)

Piping - Flow @ 2 meters/sec (6.6 feet) through pipe measuring 17 cm (6.7 in.) x 1000 meters (3,300 feet)

Capital Investment:

Facilities	
Lagoon	$ 9,000
Contingency and contractor's fee	1,170
Total facility cost	$ 10,170
Land	700
Equipment	

TABLE VIII-8. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE

SUBCATEGORY: Gold Mines (Alone)

PLANT SIZE: 320,000 **METRIC TONS (** 353,000 **SHORT TONS) PER YEAR OF** ore mined

PLANT AGE: N/A **YEARS** **PLANT LOCATION:** N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	53.8	121.2	†		
ANNUAL CAPITAL RECOVERY	7.4	17.3	†		
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	2.3	28.1	†		
ANNUAL ENERGY AND POWER COSTS	—	4.4	†		
TOTAL ANNUAL COSTS	9.7	49.8	†		
COSTS($)/METRIC TON OF PRODUCT*	0.03	0.16	†		

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	25	20	20	20		
Cu	0.06	0.06	0.05	0.05		
Hg	0.002	0.002	0.001	0.001		
Zn	6	4	0.5	0.5		
Pb	0.3	0.25	0.2	0.1		

*ORE MINED. TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: SEDIMENTATION (SETTLING POND)

LEVEL B: SEDIMENTATION, LIME PRECIPITATION, SECONDARY SETTLING, AND DISCHARGE

LEVEL C: LEVEL B + OPERATING EXPERIENCE AND CLOSER CONTROL OF OPERATING CONDITIONS IN TREATMENT SYSTEM

† NO ADDITIONAL COST INCURRED

Piping		38,000
Contingency and contractor's fee		4,940
Total equipment cost		42,940
Total Capital Investment		$ 53,810

Annual Cost:

Amortization

Facility		$ 1,035
Equipment		6,400
Total amortization	$	7,435

Operation and Maintenance (O&M)

Land		70
Facility repair and maintenance		270
Equipment repair and maintenance		1,900
Taxes		20
Insurance		55
Total O&M costs		2,315
Total Annual Cost	$	9,750

Level B: Sedimentation, Lime Precipitation, Secondary Settling, and Discharge

Level-B technology utilizes a sedimentation pond with a retention time of one day and a smaller settling pond with a 6-hour retention period. The mine water has a pH of 6; thus, addition of 0.9 kg of hydrated lime per 3.785 cubic meters (2 lb/1,000 gal) of water would raise the pH sufficiently for precipitation of metals.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level B:

Sedimentation pond - dike height of 3 m (10 ft)
top width of 3 m (10 ft)
capacity of 5,700 cubic meters (1,506,000 gal)

Settling pond - dike height cf 4 m (13 ft)
top width of 3 m (10 ft)

capacity of 1,425 cubic meters (376,000 gal)

Land - 0.5 hectare (1.24 acres)

Lime precipitation system

Piping - Flow @ 2 meters (6.6 feet)/sec through pipe measuring 17 cm (6.7 in.) x 1,100 meters (3,600 feet)

Operating-Cost Assumptions for Level B:

Lime - 317 metric tons (350 short tons)/year

Operating Personnel - 1 hr/shift, 3 hr/day

Power - 30 kW (40 hp)

Capital Investment:

Facilities

Lagoon(s)		$ 12,275
Facility subtotal		12,275
Contingency and contractor's fee		1,595
Total facility cost	$	13,870

Land	875

Equipment

Lime precipitation unit	54,400
Piping	41,800
Equipment subtotal	94,200
Contingency and contractor's fee	12,245
Total equipment cost	106,445
Total Capital Investment	$ 121,190

Annual Cost:

Amortization

Facility		$ 1,415
Equipment		15,865
Total amortization	$	17,280

Operations and Maintenance (O&M)

Land	90

Operating personnel		9,450
Facility repair and maintenance		370
Equipment repair and maintenance		4,710
Materials		12,250
Taxes		20
Insurance		1,210
Total O&M Costs	$	28,100
Electricity		4,400
Total Annual Cost	$	49,780

Gold Mills or Mine/Mills (Cyanidation Process)

In 1974 there were three known mills practicing cyanidation, with one of these operations employing both flotation and cyanidation. During late 1975 and 1976, a number (3-6) of additional operations began full scale production. These operations are predominately located in Nevada and attain zero discharge by virtue of impoundment and recycle. The range of ore milled in this subcategory is 476,000 to 1,400,000 metric tons (527,000 to 1,550,000 short tons) per year. The wastewater flow ranges from 490 to 29,900 cubic meters (130,000 to 7,900,000 gallons) per day.

The representative mill has an annual production of 1,400,000 metric tons (1,550,000 short tons) and a daily wastewater flow of 29,900 cubic meters (7,900,000 gallons).

Two levels of technology are considered. The incremental costs of achieving these levels are shown in Table VIII-9.

Wastewater Treatment/Control

Level A: Recycle

Recycle for this subcategory entails use of an impoundment system, thickeners, piping and pumps. The mine water is collected in the mill reservoir and used as makeup water in the mill cyanide leaching processes. Approximately 3,800 cubic meters (1,000,000 gallons) of wastewater are dischared daily (volume approximately equivalent to net mine water flow). The treatment of this flow is considered in Treatment Level B.

The capital and operating costs and major assumptions for attaining Level A are shown below.

TABLE VIII-9 WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Gold Mills or Mine/Mills (Cyanidation Process)

PLANT SIZE: 1,400,000 **METRIC TONS (**1,550,000 **SHORT TONS) PER YEAR OF** Ore Milled

PLANT AGE: 100 **YEARS** **PLANT LOCATION:** South Dakota

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	8,017	8,309			
ANNUAL CAPITAL RECOVERY	849.1	892.6			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	723.2	776.8			
ANNUAL ENERGY AND POWER COSTS	85.7	90.7			
TOTAL ANNUAL COSTS	1,658.0	1,760.1			
COSTS/METRIC TON OF PRODUCT*	$1.18	$1.26			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/l) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B†	C	D	E
TSS	500,000	0	0			
Cyanide	1.0	0	0			
Cu	2.9	0	0			
Hg	0.006	0	0			
Zn	0.34	0	0			

*TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: RECYCLE
LEVEL B: RECYCLE (WITH OZONATION)

†COMBINED WASTEWATER DISCHARGE EQUIVALENT TO MINEWATER FLOW IS EXPECTED TO EMPLOY OZONATION PLUS CARBON ABSORPTION AND YIELD THE FOLLOWING WATER QUALITY LEVELS: TSS $\leq$ 10 mg/l; CN $\leq$ 0.02 mg/l; Cu $\leq$ 0.05 mg/l; Hg $\leq$ 0.0001 mg/l; Zn $\leq$ 0.3 mg/l

Capital-Cost Components and Assumptions for Level A:

Tailings pond dike - dike height of 75 m (250 ft)
- top width of 10 m (30 ft)
- dike length 120 m (395 ft)

Diversion ditching - 7,400 m (24, 270 ft)

Land - 221 ha (547 acres)

Piping - 9,600 m (31,490 ft) of 60 cm (24 inch) pipe

Pumps - 8 - 100 hp slurry pumps and 2 - 20 hp water pumps

Operating-Cost Assumptions for Level A:

Power - 626 kW (840 hp)

Personnel - 116 manhours/day

Capital Investment:

Facilities	
Tailings pond dike	$4,920,000
Diversion ditching	511,000
Facility subtotal	5,431,000
Contingency and contractor's fee	706,000
Total facility cost	$6,137,000
Land	383,000
Equipment	
Piping	$1,056,000
Pumps	269,000
Equipment subtotal	1,325,000
Contingency and contractor's fee	172,000
Total equipment cost	$1,497,000
Total Capital Investment	$8,017,000

Annual Cost:

Amortization

Facilities	$ 626,000
Equipment	223,100
Total amortization	$ 849,100

Operation and Maintenance (O&M)

Land	$ 38,300
Operating personnel	365,900
Facility repair and maintenance	162,900
Equipment repair and maintenance	66,300
Taxes	9,600
Insurance	80,200
Total O&M Costs	$ 723,200
Electricity	85,700
Total Annual Cost	$1,658,000

Level B: Recycle with Ozonation of Mill Water Discharge

Level B is the same as Level A with the addition of an ozonation system to reduce the cyanide concentration in the mill water discharge.

Capital-Cost Components and Assumptions for Level B

Ozone requirement - 18 kg (40 lb) per day

Piping - 200 m (650 ft) of 20 cm (8 inch) pipe

Pump - 1 - 20 hp water pump

Annual-Cost Assumptions for Level B:

Power - 36.5 kW (49 hp)

Personnel - 12 manhours/day

Capital Investment:

Equipment

Ozonation system	$ 243,000
Piping	9,000
Pump	6,000
Equipment subtotal	258,000
Contingency and contractor's fee	34,000

Total Capital Investment	$ 292,000
Annual Cost:	
Amortization	$ 43,500
Operation and Maintenance	
Operating personnel	37,800
Equipment repair and maintenance	12,900
Insurance	2,900
Total O&M costs	53,600
Electricity	
Total Annual Cost	$ 102,100

Gold Mills (Amalgamation Process)

One known mill utilizes the process of amalgamation. It mills 163,000 metric tons (180,000 short tons) yearly and discharges 2,271 cubic meters (600,000 gallons) of wastewater daily. Three levels of technology are considered. The total costs of achieving these levels are shown in Table VIII-10.

Waste Water Treatment Control

Level A: Lime Precipitation, and Discharge

The typical mill in this subcategory has adequate impoundment systems for sedimentation purposes. To achieve level A, lime precipitation would be necessary. The addition of 0.9 kg of hydrated lime per 3.785 cubic meters (2 lb/1000 gal.) is recommended for achieving level A.

The capital and operating costs assumptions for attaining this level are given below.

Capital-Cost Components and Assumptions for Level A

Lime precipitation system - hydrated lime, stored as a slurry.

Operating-Cost Assumptions for Level A

Lime - 190 metric tons (210 short tons)/year

TABLE VIII-10. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Gold Mills (Amalgamation Process)

PLANT SIZE: 163,000 METRIC TONS (180,000 SHORT TONS) PER YEAR OF ore milled

PLANT AGE: 45 YEARS PLANT LOCATION: Colorado

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	45.2	45.3	213.5	41.5	
ANNUAL CAPITAL RECOVERY	6.7	6.7	31.8	6.2	
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	19.3	22.7	12.8	1.9	
ANNUAL ENERGY AND POWER COSTS	2.0	2.0	-	1.5	
TOTAL ANNUAL COSTS	28.0	31.4	44.6	9.6	
COSTS/METRIC TON OF PRODUCT*	0.17	0.19	0.27	0.06	

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	250,000	20	20	20	0	
Cu	0.6	0.05	0.05	0.05	0	
Hg	0.002	0.0004	0.0001	<0.0001	0	
Zn	1.3	0.2	0.2	0.2	0	

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: LIME PRECIPITATION AND DISCHARGE
LEVEL B: LEVEL A PLUS SULFIDE PRECIPITATION
LEVEL C: PROCESS CHANGE FROM AMALGAMATION TO CYANIDATION
LEVEL D: TOTAL RECYCLE (ZERO DISCHARGE)

Operating personnel 1 hr/shift, 3 hr/day

Power - 20 HP

Capital Investment

Equipment

Lime precipitation system	$ 40,000
Contingency and contractor's fee	5,200
Total Equipment Cost	$ 45,200
Total Capital Investment	$ 45,200

Annual Cost:

Amortization	$ 6,720

Operation and Maintenance (O&M)

Operating Personnel	$ 9,450
Equipment repair & maintenance	2,000
Materials	7,350
Insurance	450
Total O&M Costs	19,250
Electricity	2,000
Total Annual Cost	$ 27,970

Level B: Level A, Sulfide Precipitation and Discharge

Level B requires the addition of 1.5 mg/l of sodium sulfide to the wastewater stream. Costs for sulfide precipitation are shown below. Total Level B costs are shown in Table VIII-10.

Capital-Cost Components and Assumptions for Level B

Sodium sulfide distribution system

Operating-Cost Assumptions for Level B

Sodium sulfide 1,192 kg (2,627 lb)/year

Operating personnel 1 hr/day

Capital Investment:

Equipment

Sulfide precipitation unit	$	100
Contingency and contractor's fee		15
Total Equipment Cost	$	115

Amortization	$	15

Operation and Maintenance (O&M)

Operation personnel	$	3,150
Equipment repair & maintenance		5
Materials		210
Total O&M Costs	$	3,365
Total Annual Cost	$	3,380

Level C: Process Change from Amalgamation to Cyanidation

An alternative to precipitation for this subcategory would be to change the milling process from amalgamation to cyanidation. The costs incurred for this process change are difficult to obtain and estimate. However, data were provided for a similar change for an operation whose mill-circuit volume is 10 times greater than the one in this subcategory. To estimate the cost for the process change, an application of the six-tenths-factor rule was used.

Note that a mill with a water flow of 22,710 cubic meters (6,000,000 gal)/day incurred a capital investment cost of $850,000 for the process change. Applying the six-tenths-factor rule to an operation whose water flow is 2,271 cubic meters (600,000 gal)/day resulted in a capital investment cost of $213,510. No assumptions were made as the the amounts of materials, operating labor, and power that would be required, as these data are not available. Equipment repair and maintenance were assumed to total 5 percent of capital investment. Amortization was assumed over a 10-year period. The costs are shown in Table VIII-10.

The capital and operating costs for attaining this level are shown below.

Capital Investment:

Equipment

Process change	$ 213,510

Annual Cost:

Amortization	$ 31,820

Operation and Maintenance (O&M)

Equipment repair and maintenance	$ 10,675
Insurance	2,135
Total O&M costs	12,810
Total Annual Cost	$ 44,630

Level D: Total Recycle (Zero Discharge)

To achieve total recycle, additional pumps and piping would be necessary to recirculate the wastewater. The capital and operating cost components and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level C:

Piping - Flow @ 2 meters (6.6 feet)/second through pipe measuring 13 cm (5.1 in.) x 1000 meters (3,300 feet)

Pumps - water pumps with capacity of 15.77 cubic meters (4,166 gal)/minute

Operating-Cost Assumptions for Level C:

Power - 11.2 kW (15 hp)

Capital Investment:

Equipment

Piping	$ 32,000
Pumps	4,700
Equipment subtotal	36,700
Contingency and contractor's fee	4,770
Total Capital Investment	$ 41,470

Annual Cost:

Amortization	$ 6,170

Operation and Maintenance (O&M)

Equipment repair and maintenance	$ 1,835
Insurance	40
Total O&M costs	1,875
Electricity	1,500
Total Annual Cost	$ 9,545

Gold Mills (Flotation)

The one mill which exists in this subcategory processes 50,000 metric tons (55,000 short tons) of ore annually. The flow from the mill is 490 cubic meters (130,000 gallons) per day. A discharge from the tailing pond occurs for only two months of the year and amounts to 545 cubic meters (144,000 gallons) per day.

Two alternative treatment levels are considered. The costs of achieving these levels are shown in Table VIII-11.

Waste Water Treatment Control

Level A: Diversion Ditching, Lime Precipitation, and Alkaline Chlorination

Adequate impoundment systems exist for the mill in this subcategory. Lime precipitation is recommended for the precipitation of metals. The recommended dosage is 0.9 kg of hydrated lime per 3.785 cubic meters (2 lb/1000 gal) of wastewater. Control is also needed to divert seasonal runoff that results in tailing-pond overflow.

Cyanide is used in the flotation process. Should an accidental discharge occur, chlorination of the cyanide solution would be necessary. The amount of chlorine needed would depend upon the amount of cyanide in the wastewater. Since discharge of cyanide is not a typical occurence, no estimate of the amount of chlorine has been made.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Diversion ditching - total of 1000 meters (3,280 feet)

TABLE VIII-11. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Gold Mills (Flotation)

PLANT SIZE: 50,000 METRIC TONS (~55,000 SHORT TONS) PER YEAR OF ore milled

PLANT AGE: 39 YEARS PLANT LOCATION: Washington

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	20.3	31.2			
ANNUAL CAPITAL RECOVERY	3.5	4.5			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	12.1	12.6			
ANNUAL ENERGY AND POWER COSTS	1.0	1.0			
TOTAL ANNUAL COSTS	16.6	18.1			
COSTS/METRIC TON OF PRODUCT*	0.33	0.36			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	240,000	20	0			
Cyanide	109	0.01	0			
Hg †	0.005	0.001	0			
Cu	10.8	0.05	0			
Zn	79	0.2	0			
Cd †	0.10	0.05	0			
Pb †	0.40	0.2	0			

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907

† HYPOTHETICAL - BASED ON OPERATIONS VISITED IN SUBCATEGORY

LEVEL A: DIVERSION DITCHING, LIME PRECIPITATION, AND ALKALINE CHLORINATION

LEVEL B: LEVEL A PLUS SETTLING POND — NO DISCHARGE

Alkaline chlorinator - V-notch type; data supplied from surveyed operation

Lime precipitation - 15-day supply of lime slurry. Mix tank with capacity of 7.4 cubic meters (1,955 gal) for slurry storage. Mix tank with capacity of 5.2-cubic meters (1,374 gal) for 15-minute retention.

Slurry pump - 0.34 cubic meter (90 gal)/minute

Operating-Cost Assumptions for Level A:

Lime - 41 metric tons (46 short tons)/year

Operating personnel - 3 hr/day

Power - 7.5 kW (10 hp)

Capital Investment:

Facilities

Diversion ditching	$	1,650
Contingency and contractor's fee		215
Total facility cost	$	1,875

Equipment

Lime precipitation unit		6,400
Aklaline chlorinator		5,660
Pumps		4,200
Equipment subtotal		16,260
Contingency and contractor's fee		2,115
Total equipment cost		18,375
Total Capital Investment	$	20,250

Annual Cost:

Amortization

Facility		190
Equipment		3,505
Total amortization	$	3,505

Operation and Maintenance (O&M)

Operating personnel	9,450
Facility repair and maintenance	50
Equipment repair and maintenance	815
Materials	1,610
Insurance	200
Total O&M costs	12,125
Electricity	1,000
Total Annual Cost	$ 16,630

Level B: Level A plus Settling Pond - No Discharge

To avoid discharge of the seasonal runoff, an additional settling pond will be necessary. The runoff would be collected in the settling pond and stored for use as mill process water. A five-day retention time is assumed.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level B:

Pond - dike height of 3 m (10 ft)
top width of 3 m (10 ft)
capacity of 5,700 cubic meters (1,506,000 gal)

Land - 0.4 hectare (1 acre)

Capital Investment:

Facilities

Lagoon	$ 9,000
Contingency and contractor's fee	1,170
Total facility cost	$ 10,170
Total Capital Investment	$ 10,870

Annual Cost:

Amortization	$ 1,035

Operation and Maintenance (O&M)

Land	$ 70

Facility repair and maintenance	270
Taxes	20
Insurance	110
Total O&M costs	470
Total Annual Cost	$ 1,505

Gold Mine/Mills Employing Gravity Separation

There are approximately 200 known placer operations at present. The Bureau of Mines estimated that, at the 68 operations known in 1972, the amount of material washed totaled 698,445 cubic meters (913,000 cubic yards) per year (Reference 2). Assuming that the material moved on the average by the industry is proportional from year to year, a conservative estimate of 2,054,000 cubic meters (2,690,000 cubic yards) can be obtained. The wastewater flow is 11,355 to 15,140 cubic meters (3,000,000 to 4,000,000 gallons) per day. The placer mining industry, for the most part, is located in Alaska. The mining season there lasts for approximately 100 to 120 days, depending upon location. It has been reported by some members of the industry that, in surface-stripping operations, 765 cubic meters (1,000 cubic yards) of material can be moved in an eight-hour day. Both the length of the mining season and the amount of material moved can be significantly modified due to "down time" caused by mechanical failure or poor weather.

A hypothetical operation based on an arithmetic average of 68 operations from Reference 2, was selected as representative for this subcategory. The annual material handled for the representative operation is 10,270 cubic meters (13,425 cubic yards). Assuming a specific gravity of 2.65 for this material, the total weight handled is 27,215 metric tons (30,000 short tons) each year. This estimate does not include overburden but rather ore washed. The assumed daily water flow is 13,247 cubic meters (3,500,000 gallons).

Four alternative levels of technology are considered.

The capital and operating costs of achieving these levels are shown in Table VIII-12.

Waste Water Treatment/Control

Level A: Settling Pond

TABLE VIII-12. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE/MILL

SUBCATEGORY: Gold Mine/Mills Employing Gravity Separation

PLANT SIZE: 27,215 **METRIC TONS (** 30,000 **SHORT TONS) PER YEAR OF** ore milled

PLANT AGE: N/A **YEARS** **PLANT LOCATION:** N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	12.9	34.4	47.3	57.5	
ANNUAL CAPITAL RECOVERY	1.2	5.1	6.3	7.8	
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	0.6	9.5	10.1	40.5	
ANNUAL ENERGY AND POWER COSTS	--	4.0	4.0	4.1	
TOTAL ANNUAL COSTS	1.8	18.6	20.4	52.4	
COSTS ($)/METRIC TON OF PRODUCT*	0.066	0.68	0.75	1.93	

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (ml/l)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
Settleable Solids	3-200	0.5	0.5	<0.5	<0.5	

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907.

LEVEL A: SETTLING POND
LEVEL B: DISTRIBUTION SYSTEM
LEVEL C: SETTLING POND AND DISTRIBUTION SYSTEM
LEVEL D: SETTLING POND, DISTRIBUTION SYSTEM, AND FLOCCULATION

The recommended treatment system for level A consists of a settling pond for removal of suspended solids. The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Settling pond - dike height of 3 m (10 ft)
top width of 3 m (10 ft)
capacity of 7,380 cubic meters (1,950,000 gal)

Land - 0.4 hectare (1 acre)

Capital Investment:	
Facilities	
Lagoon	$ 10,800
Contingency and contractor's fee	1,405
Total facility cost	$ 12,205
Land	700
Total Capital Investment	$ 12,905
Annual Cost:	
Amortization	$ 1,245
Operation and Maintenance	
Land	70
Facility repair and maintenance	325
Taxes	20
Insurance	130
Total O&M costs	545
Total Annual Cost	$ 1,790

Level B: Distribution System

An alternative to level-A treatment would be to construct and utilize a process-water distribution system. The purpose would be to deliver dredge wastewater to all mine workings for filtration. The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level B:

Piping - Flow @ 1 m (3.3 ft)/sec through pipe measuring 45 cm (17.7 in.) x 100 meters (330 feet)

Pumps - slurry type (plus one standby)

Operating-Cost Assumptions for Level B:

Power - 30 kW (40 hp)

Distribution system maintenance @ 30% of system capital cost

Capital Investment:

Equipment	
Piping	$ 8,400
Pumps	22,000
Equipment subtotal	30,400
Contingency and contractor's fee	3,950
Total Capital Investment	$ 34,350

Annual Cost:

Amortization	$ 5,120
Operation and Maintenance (O&M)	
Distribution system maintenance	$ 9,120
Insurance	345
Total O&M costs	9,465
Electricity	4,000
Total Annual Cost	$ 18,585

Level C: Settling Pond and Distribution System

Level C is the sum of levels A and B. Total invested capital and annual operating costs for this level are shown in Table VIII-12.

Level D: Settling Pond, Distribution System, and Flocculation

Level D is the same as level C plus the addition of a flocculant for further suspended-solid removal. It is assumed that 2 mg/l of flocculant is added. A simple flocculant feed system is all that is needed. The incremental capital and operating ccsts and assumptions for this system are shown below. The total system cost is shown in Table VIII-12.

Capital-Cost Components and Assumptions for Level D:

Flocculant feed system

Operating-Cost Assumptions for Level D:

Operating personnel - 3 hr/day

Flocculant - 9,267 kg (20,430 lb)/year

Power - 0.75 kW (1 hp)

Capital Investment:

Equipment

Flocculant feed system	$	9,000
Contingency and contractor's fee		1,170
Total Capital Investment	$	10,170

Annual Cost:

Amortization	$	1,515
Operation and Maintenance (O&M)		
Operating personnel		9,450
Equipment repair and maintenance		450
Materials		20,430
Insurance		100
Total O&M costs	$	30,430
Electricity		100
Total Annual Cost	$	32,045

WASTE WATER-TREATMENT COSTS FOR SILVER-ORE CATEGORY

Silver-Ore Mines

There are five known major silver mines in operation. The range of ore mined is 75,280 to 1,428,000 metric tons (83,000 to 1,574,000 short tons) annually. The mine wastewater ranges from 246 to 4,920 cubic meters (65,000 to 1,300,000 gallons) daily.

Three of these mines are associated with mills. The remaining two are mines alone.

A hypothetical mine, based on an arithmetic average of the five known mines, was selected as representative for this subcategory. The annual ore mined is 181,400 metric tons (200,000 short tons). The average daily discharge amounts to 1,700 cubic meters (450,000 gallons). Three levels of technology are considered. The total costs of achieving these levels are shown in Table VIII-13.

Waste Water Treatment/Control

Level A: Sedimentation (Settling Pond)

It is assumed that a typical silver mining operation has little or no effluent treatment or control. Level-A technology requires the construction of a settling pond with a 10-day retention capacity and adequate piping. No costs are shown for pumps, since mine dewatering facilities are already installed.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Settling pond - dike height of 3 m (10 ft)
top width of 3 m (10 ft)
capacity of 25,500 cubic meters (6,736,000 gallons)

Land - 1.3 hectares (3.2 acres)

Piping - Flow @ 2 m (6.6 ft)/sec through pipe measuring 12 cm (4.8 in.) x 1000 meters (3,280 feet)

Capital Investment:

Facilities

Lagoon	$ 26,000

TABLE VIII-13. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE

SUBCATEGORY: Silver-Ore Mines

PLANT SIZE: 181,400 METRIC TONS (200,000 SHORT TONS) PER YEAR OF ore mined

PLANT AGE: N/A YEARS PLANT LOCATION: N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	65.6	114.6	114.7	†	
ANNUAL CAPITAL RECOVERY	8.0	15.0	15.0	†	
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	3.0	20.5	23.4	†	
ANNUAL ENERGY AND POWER COSTS	—	2.0	2.0	†	
TOTAL ANNUAL COSTS	11.0	37.5	40.4	†	
COSTS($)/METRIC TON OF PRODUCT*	0.06	0.21	0.22	†	

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	25	20	20	20	20	
Cu	0.1	0.09	0.05	0.05	0.05	
Pb	0.2	0.19	0.2	0.2	0.1	
Zn	0.7	0.6	0.5	0.5	0.5	
Hg	0.004	0.003	0.002	0.001	0.001	

*ORE MINED. TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: SEDIMENTATION (SETTLING POND)
LEVEL B: SEDIMENTATION, LIME PRECIPITATION, AND SECONDARY SETTLING
LEVEL C: LEVEL B PLUS SULFIDE PRECIPITATION
LEVEL D: LEVEL C PLUS OPERATING EXPERIENCE AND CLOSER CONTROL OF OPERATING CONDITIONS OF TREATMENT SYSTEM

† NO ADDITIONAL COST INCURRED

Contingency		3,380
Total facility cost	$	29,380
Land		2,275
Equipment		
Piping		30,000
Contingency and contractor's fee		3,900
Total equipment cost		33,900
Total Capital Investment	$	65,555

Annual Cost:

Amortization		
Facility	$	2,990
Equipment		5,050
Total amortization	$	8,040
Operation and Maintenance (O&M)		
Land		20
Facility repair and maintenance		780
Equipment repair and maintenance		1,500
Taxes		55
Insurance		655
Total O&M costs		3,010
Total Annual Cost	$	11,050

Level B: Sedimentation, Lime Precipitation, and Secondary Settling

The incremental cost to achieve level B is the cost for a lime precipitation system, additional piping, and a secondary settling pond. The costs associated with sedimentation are shown under Level A.

The recommended treatment consists of the addition of 0.9 kg of hydrated lime per 3.785 cubic meters (2 lb/1000 gallons) of mine wastewater. The mine wastewater is then retained for one day in a settling pond before discharge. The incremental capital and operating costs and assumptions for attaining level B are shown below. The total system cost is shown in Table VIII-13.

Lime precipitation system

Piping - Flow @ 2 m (6.6 ft)/sec through pipe measuring
12 cm (4.7 in.) x 100 meters (328 feet)

Settling pond - dike height of 3 m (10 ft)
top width of 3 m (10 ft)
capacity of 2,550 cubic meters (674,000 gal)

Land - 0.21 hectare (0.5 acre)

Operating-Cost Assumptions for Level B:

Lime - 142 metric tons (157.5 short tons)/year

Power - 14.9 kW (20 hp)

Operating personnel - 3 hr/day

Capital Investment:

Facilities

Lagoon	$ 5,100
Contingency and contractor's fee	665
Total facility cost	$ 5,765

Land	365

Equipment

Lime precipitation system	$ 35,000
Piping	3,000
Equipment subtotal	38,000
Contingency and contractor's fee	4,940
Total equipment cost	$ 42,940
Total Capital Investment	$ 49,070

Annual Cost:

Amortization

Facility	$ 585
Equipment	6,400
Total amortization	$ 6,985

Operation and Maintenance (O&M)

Land	35
Operating personnel	9,450
Facility repair and maintenance	155
Equipment repair and maintenance	1,900
Materials	5,510
Taxes	10
Insurance	490
Total O&M costs	17,550
Electricity	2,000
Total Annual Cost	$ 26,535

Level C: Level B plus Sulfide Precipitation

Level-C technology includes the addition of sodium sulfide plus level-B technology.

Further removal of metals is attained by the addition of 2 mg/l of sodium sulfide. The incremental capital and operating costs and assumptions for sulfide precipitation are shown below. The total cost to achieve level C is shown in Table VIII-13.

Capital-Cost Components and Assumptions for Level C:

Sulfide precipitation system

Operating-Cost Assumptions for Level C:

Sodium sulfide - 1,191 kg (2,625 lb)/year

Operating personnel - 1 hr/day

Capital Investment:

Equipment

Sulfide precipitation system	$ 100
Contingency and contractor's fee	15
Total Capital Investment	$ 115

Annual Cost:

Amortization	15

Operation and Maintenance (O&M)

Operating personnel	$ 3,150
Equipment repair and maintenance	5
Materials	265
Total O&M costs	$ 3,420
Total Annual Cost	$ 3,425

Silver Mills Employing Cyanidation, Amagamation, Gravity Separation, and Byproduct Recovery

Five subcategories based on milling process have been identified for the silver milling industry. The subcategories are essentially identical to those of the gold industry. Four of the silver milling subcategories (cyanidation, amalgamation, gravity separation, and byproduct recovery) are represented by the same operation and require the same control and treatment technology as the gold milling industry. The capital and annual operating costs of implementing the required treatment technologies for these subcategories are shown in Tables VIII-9, VIII-10, and VIII-12.

The remaining subcategory and applicable treatment technologies are identified in the section which follows.

Silver Mills Employing Flotation Process

There are four major mills in this subcategory. These mills process ore in the range of 75,280 to 182,300 metric tons (83,000 to 201,000 short tons) annually. Daily wastewater flow from these mills ranges from 1,500 to 3,160 cubic meters (396,000 to 835,000 gallons).

An existing flotation mill which mills 180,000 metric tons (200,000 short tons) of ore and has a daily water flow rate of 3,160 cubic meters (835,000 gallons) was selected as a representative operation. Typically, mills in this subcategory recycle 70 percent of their wastewater and discharge the remaining 30 percent.

Two levels of technology are considered. The cost of implementing this level is shown in Table VIII-14.

Waste Water Treatment/Control

TABLE VIII-14. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Silver Mills Employing Flotation Process

PLANT SIZE: 180,000 METRIC TONS (200,000 SHORT TONS) PER YEAR OF ore milled

PLANT AGE: 23 YEARS PLANT LOCATION: Idaho

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	55.0	39.0			
ANNUAL CAPITAL RECOVERY	8.1	5.7			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	22.4	2.1			
ANNUAL ENERGY AND POWER COSTS	4.5	0.3			
TOTAL ANNUAL COSTS	35.0	8.1			
COSTS($)/METRIC TON OF PRODUCT*	0.19	0.045			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW ** (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	290,000	20	0			
Cyanide	0.03	0.01	0			
Cd**	0.06	0.05	0			
Cu	0.25	0.05	0			
Hg	0.0098	0.001	0			
Pb	0.42	0.2	0			
Zn	0.37	0.2	0			

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: DIVERSION DITCHING' LIME PRECIPITATION

LEVEL B: TOTAL RECYCLE

**HYPOTHETICAL

Level A: Diversion Ditching, Lime Precipitation

Adequate impoundment systems exist for mills in this subcategory. Lime precipitation is recommended for the precipitation of dissolved metals. The recommended dosage is 0.9 kg of hydrated lime per 3.785 cubic meters (2 lb/1000 gallons) of wastewater. Control is also needed to divert seasonal runoff that results in tailing pond overflow.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Lime precipitation system - to treat 3,160 cubic meters (835,000 gallons) of wastewater daily

Diversion ditching - total of 1000 meters (3,280 feet)

Operating-Cost Assumption for Level A:

Lime - 263 metric tons (390 short tons)/year

Operating personnel - 3 hr/day

Power - 39 kw (44 hp)

Capital Investment:

Facilities

Diversion ditching	$1,650
Contingency and contractor's fee	215
Total facility cost	$ 1,865

Equipment

Lime precipitation unit	47,000
Contingency and contractor's fee	6,110
Total equipment cost	53,110
Total Capital Investment	$ 54,975

Annual Cost:

Amortination

Facility	$ 190

Equipment	7,915
Total amortination	$ 8,105

Operation and Maintenance (O&M)

Operating personnel	$9,450
Facility repair and maintenance	50
Equipment repair and maintenance	2,350
Material	10,000
Insurance	550
Total O&M	$ 22,400

Electricity	4,490
Total Annual Cost	$ 34,995

Level B: Total Recycle (No Discharge)

Total recycle for this subcategory entails the implementation of additional pumps and pipes to recirculate the effluent that is normally discharged. In this case, it is approximately 946 cubic meters (250,000 gallons) a day. Also, diversion ditching is recommended to avoid tailing-pond overflow resulting from seasonal runoff.

Capital-Cost Components and Assumptions for Level B:

Piping - Flow @ 1 m (3.3 ft)/sec through pipe measuring 11 cm (4.3 in.) in diameter

Water pumps - 0.66 cubic meter (174 gal)/minute

Diversion ditching - 1000 meters (3,300 feet) long

Operating-Cost Assumptions for Level B:

Power - 2.2 kW (3 hp)

Capital Investment:

Facilities

Diversion ditching	$ 1,650
Contingency and contractor's fee	215
Total facility cost	$ 1,865

Equipment

Piping	30,000

Pumps		2,900
Equipment subtotal		32,900
Contingency and contractor's fee		4,280
Total equipment cost		37,180
Total Capital Investment	$	39,045
Annual Cost:		
Amortization		
Facility	$	190
Equipment		5,540
Total amortization	$	5,730
Operation and Maintenance (O&M)		
Facility repair and maintenance		50
Equipment repair and maintenance		1,645
Insurance		390
Total O&M costs		2,085
Electricity		300
Total Annual Cost	$	8,115

WASTE WATER-TREATMENT COSTS FOR BAUXITE CATEGORY

Bauxite Mines

There are currently two bauxite mines in operation in the U.S. Both operations treat a portion of their mine drainage with lime and then allow the effluent to settle in a series of ponds. Of the two sites (both visited), one was chosen as the industry representative. Note that mines in this subcategory typically have more than one discharge, and some of these discharges are treated. The remaining wastewater is discharged directly to nearby streams. It has been recommended that all discharges be treated.

The representative mine produces 861,650 metric tons (950,000 short tons) of ore yearly. The average untreated mine drainages for the representative operation consist of three discharges with flow rates of 17,000, 7,570, and 3,785 cubic meters (4,500,000, 2,000,000, and 1,000,000 gallons, respectively) per day into pits. Each discharge must be treated separately because of the great distance between each pit. One level of technology is considered for this subcategory. The incremental cost of implementing this level is shown in Table VIII-15.

Waste Water Treatment/Control

Level A: Lime Precipitation and Secondary Settling

The typical bauxite mine has dewatering pumps, pipes, and primary settling ponds. The installation of additional piping, a lime precipitation system, and secondary settling ponds for each discharge is needed to achieve level A.

The addition of 0.9 kg of hydrated lime per 3.785 cubic meters of mine water (2 lb/1000 gallons), followed by a 2-day retention in the secondary settling ponds, is considered adequate treatment for this subcategory.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Three lime precipitation units -
    17,000 cubic meters (4,500,000 gal)/day
    7,570 cubic meters (2,000,000 gal)/day
    3,785 cubic meters (1,000,000 gal)/day

Three secondary settling ponds -
    all have dike height of 3 m (10 ft) and are 3 meters (10 ft) wide
    capacities of 50,000 cubic meters (13,209,000 gal)
    25,000 cubic meters (6,604,000 gal)
    12,000 cubic meters (3,170,000 gal)

Piping - Flow @ 2 m (6.6 ft)/sec through pipes measuring:
    36 cm (14 in.) x 100 meters (328 feet)
    24 cm (9.4 in.) x 100 meters (328 feet)
    17 cm (6.7 in.) x 100 meters (328 feet)

Land - 4.3 hectares (10.6 acres)

Operating-Cost Assumptions for Level A:

Lime - 2,380 metric tons (2,625 short tons)/year

TABLE VIII-15. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE

SUBCATEGORY: Bauxite Mines

PLANT SIZE: 861,650 **METRIC TONS (** 950,000 **SHORT TONS) PER YEAR OF** ore mined

PLANT AGE: 75 **YEARS** **PLANT LOCATION:** Arkansas

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	383.2	†			
ANNUAL CAPITAL RECOVERY	51.7	†			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	149.5	†			
ANNUAL ENERGY AND POWER COSTS	25.3	†			
TOTAL ANNUAL COSTS	226.5	†			
COSTS($)/METRIC TON OF PRODUCT*	0.26	†			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	161.0	20	20			
Al	47.8	0.6	0.5			
Fe	39.2	0.5	0.30			
Zn	0.23	0.1	0.1			

*ORE MINED. TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

†NO COST DIFFERENCE

LEVEL A: LIME PRECIPITATION AND SECONDARY SETTLING

LEVEL B: LIME PRECIPITATION AND SECONDARY SETTLING WITH OPTIMUM pH CONTROL

Power - 186 kW (250 hp)

Operating personnel - 3 hr/day/unit = 12 hr/day

Capital Investment:

Facilities

Lagoon(s)	$ 80,200
Contingency and contractor's fee	10,425
Total facility cost	$ 90,625

Land	7,525

Equipment

Lime precipitation units	$ 236,650
Piping	15,600
Equipment subtotal	252,250
Contingency and contractor's fee	32,795
Total equipment cost	$ 285,045
Total Capital Investment	$ 383,195

Annual Cost:

Amortization

Facility	$ 9,230
Equipment	42,480
Total amortization	$ 51,710

Operation and Maintenance (O&M)

Land	750
Operating personnel	37,800
Facility repair and maintenance	2,405
Equipment repair and maintenance	12,615
Materials	91,875
Taxes	190
Insurance	3,830
Total O&M costs	$ 149,465

Electricity	25,365

Total Annual Cost $ 226,540

WASTE WATER TREATMENT COSTS FOR FERROALLOY-ORE CATEGORY

Ferroalloy-Ore Mines

There are seven ferroalloy mines in this subcategory. The annual ore production ranges from 16,560 to 14,000,000 metric tons (18,220 to 15,500,000 short tons). The range of daily wastewater discharged is 0 to 51,840 cubic meters (0 to 13,700,000 gallons).

A hypothetical mine, based on the industry average, was selected as representative. This mine is assumed to have an annual ore production of 1,800,000 metric tons (1,990,000 short tons), with a daily discharge of 3,275 cubic meters (865,000 gallons).

The current level of technology for this subcategory includes flocculation, neutralization, and settling or clarifying. A further level of technology has been recommended. The total costs of achieving this level are shown in Table VIII-16.

Waste Water Treatment/Control

Level A: Lime Precipitation and Secondary Settling

The necessary equipment includes a lime precipitation unit and a settling pond. The addition of 0.9 kg of hydrated lime per 3.785 cubic meters (2 lb/1000 gallons) of wastewater is considered sufficient for precipitation of metals. The wastewater is then retained for one day in a settling pond before discharge. The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assemptions for Level A:

Lime precipitation system

Settling pond - dike height of 3 meters (10 feet)
top width of 3 meters (10 feet)
capacity of 4,900 cubic meters (1,295,000 gal)

Land - 0.35 hectare (0.85 acre)

TABLE VIII-16. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE

SUBCATEGORY: Ferroalloy-Ore Mines

PLANT SIZE: 1,800,000 METRIC TONS (1,990,000 SHORT TONS) PER YEAR OF ore mined

PLANT AGE: N/A YEARS PLANT LOCATION: N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	93.8	†			
ANNUAL CAPITAL RECOVERY	14.0	†			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	25.1	†			
ANNUAL ENERGY AND POWER COSTS	12.5	†			
TOTAL ANNUAL COSTS	51.6	†			
COSTS($)/METRIC TON OF PRODUCT*	0.028	†			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	50	20	20			
As	1	0.5	0.5			
Cd	0.14	0.05	0.05			
Cu	0.5	0.05	0.05			
Mo	2	1.0	1.0			
Pb	0.25	0.2	0.1			
Zn	0.6	0.5	0.1			

*ORE MINED. TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

†NO COST DIFFERENCE

LEVEL A: LIME PRECIPITATION AND SECONDARY SETTLING

LEVEL B: LEVEL A WITH OPERATING EXPERIENCE AND CLOSER CONTROL OF OPERATING CONDITIONS

Piping - Flow @ 2 meters (6.6 feet)/second through pipe measuring 16 cm (6.3 in.) x 100 meters (328 ft)

Operating-Cost Assumptions for Level A:

Lime - 275 metric tons (302 short tons)/year
Operating personnel - 3 hr/day
Power - 32 kW (43 hp)

Capital Investment:

Facilities	
Lagoon	$ 8,000
Contingency and contractor's fee	1,040
Total facility cost	$ 9,040
Land	615
Equipment	
Lime precipitation unit	49,000
Piping	3,700
Equipment subtotal	52,700
Contingency and contractor's fee	6,850
Total equipment cost	59,550
Total Capital Investment	$ 69,205

Annual Cost:

Amortization	
Facility	$ 920
Equipment	8,875
Total amortization	$ 9,795
Operation and Maintenance (O&M)	
Land	60
Operating personnel	9,450
Facility repair and maintenance	240
Equipment repair and maintenance	2,635
Materials	10,570
Taxes	15
Insurance	690
Total O&M costs	23,660
Electricity	4,320

Total Annual Cost	$ 37,775

Ferroalloy Mine/Mills Annually Processing Less Than 5,000 Metric Tons (5,500 Short Tons) Ore By Methods Other Than Ore Leaching Ore Leaching

There are 50-60 operations in this subcategory. All are located in the western U.S. The annual amount of ore milled ranges from 0 to 5,000 metric tons (0 to 5,500 short tons). The daily wastewater flow ranges from 0 to 1,872 cubic meters (0 to 500,000 gallons).

Mills in this subcategory are small and operate 100 days a year or less. The mine associated with each mill is assumed to discharge 350 days and to require treatment of the mine water year-round.

A typical operation in this subcategory mines and mills approximately 500 metric tons (550 short tons) a year. The daily wastewater flow is 55 cubic meters (14,500 gallons).

Two levels of technology are considered. The costs of achieving these levels are shown in Table VIII-17.

Waste Water Treatment Control

Level A: Settling Pond

The equipment and facilities necessary to achieve this level include a pond and additional piping.

The capital and operating costs are as follows:

Capital Inverstment:

Facilities

Settling Pond	$ 500
Contingency and contractor's fee	65
Total facility cost	$ 565

Equipment

Piping	$ 1,000
Contingency and contractor's fee	130
Total equipment cost	1,130

TABLE VIII-17. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Ferroalloy Mine/Mill Annually Processing Less than 5000 Metric Tons (5,500 Short Tons) Ore by Methods Other than Ore Leaching

PLANT SIZE: 500 METRIC TONS (550 SHORT TONS) PER YEAR OF ore mined and milled

PLANT AGE: N/A YEARS PLANT LOCATION: N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	1.7	5.4	8.8		
ANNUAL CAPITAL RECOVERY	0.23	0.78	1.29		
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	0.08	0.37	0.62		
ANNUAL ENERGY AND POWER COSTS	-	0.25	0.50		
TOTAL ANNUAL COSTS	0.31	1.40	2.41		
COSTS/METRIC TON OF PRODUCT*	0.62	2.80	4.82		

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	250,000	30	30	30		

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: SETTLING POND
LEVEL B: LEVEL A PLUS pH CONTROL
LEVEL C: LEVEL B PLUS FLOCCULATION

Total Capital Investment	$ 1,695

Annual Cost:

Amortization

Facility	$ 60
Equipment	170
Total amortization	$ 230

Operation and Maintenance (O&M)

Facility repair and maintenance	15
Equipment repair and maintenance	50
Insurance	15
Total O&M Cost	80
Total Annual Cost	$ 310

Level B: Settling Pond and pH Control at Selected Operations

A few operations in this subcategory will need to raise the pH of their mine water from about 5 to a minimum of 6.5. To do this the addition of 0.45 kg of lime per 3.785 cubic meters (1 lb/1000 gallons) of wastewater is recommended. Cost for operating personnel is not included. It is assumed that the owners of these operations do the necessary work themselves.

The incremental capital and operating costs for Level B are shown below. The total costs of achieving Level B are shown in Table VIII-17.

Capital Investment:

Equipment

Mixing tank	$1400
Slurry Pump	1875
Equipment subtotal	3275
Contingency and contractor's fee	425
Total Capital Investment	$3700

Annual Cost:

Amortization

Operation and Maintenance (O&M)

Equipment repair and maintenance	$ 165
Materials	85
Insurance	40
Total O&M Costs	$ 290

Electricity

Total Annual Cost	$1095

Level C: Level B plus Flocculation

In addition to Level B treatment, flocculation would be necessary for mill water at selected operations. This would be needed for only 100 days a year.

A full day supply of flocculant, in a 0.2 percent solution that is prepared daily, is fed to the wastewater stream at a rate of 5 mg/l. The total cost of Level C treatment is shown in Table VIII-17.

The incremental costs for achieving Level C are shown below.

Capital Investment:

Equipment

Mixing tank	$ 1300
Feed pump	1700
Equipment subtotal	3000
Contingency and contractor's fee	390
Total Capital Investment	$3390

Annual Cost:

Amortination	505

Operation and Maintenance (O&M)

Equipment repair and maintenance	$ 150
Materials	60
Insurance	35
Total A&M Costs	245

Electricity	255

Total Annual Cost $ 1005

Ferroalloy Mills Annually Processing More Than 5,000 Metric Tons (5,500 Short Tons) Ore By Physical Methods

There are two mills in this subcategory, both of which are located in the western U.S. The annual amount of ore milled ranges from 7,200 to 1,800,000 metric tons (7,925 to 1,990,000 short tons). The daily wastewater flow ranges from 30 to 17,425 cubic meters (7,925 to 4,603,700 gallons).

A hypothetical mill was chosen to represent this subcategory. The average annual milling capacity is 525,000 metric tons (577,500 short tons), with a daily discharge of 4,920 cubic meters (1,300,000 gallons).

Three alternative levels of technology are considered. The total costs of implementing these levels are shown in Table VIII-18.

Waste Water Treatment/Control

Level A: Lime Precipitation

Level-A treatment consists of lime precipitation and settling. The necessary settling ponds are currently available; therefore, no cost estimates for these facilities have been made. The addition of 1.36 kg of hydrated lime per 3785 cubic meters (3 lb/1000 gallons) of water would be necessary to raise the pH sufficiently for precipitation of metals.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Lime precipitation system

Operating-Cost Assumptions for Level A:

Lime - 618 metric tons (682 short tons)/year

Operating personnel - 3 hr/day

Power - 37 kW (50 hp)

TABLE VIII-18. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Ferroalloy Mills Annually Processing More Than 5,000 Metric Tons (5,512 Short Tons) Ore by Physical Methods

PLANT SIZE: 525,000 **METRIC TONS (** 577,500 **SHORT TONS) PER YEAR OF** ore milled

PLANT AGE: N/A **YEARS** **PLANT LOCATION:** N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL A	B	C	D	E
TOTAL INVESTED CAPITAL	70.0	64.2	134.2		
ANNUAL CAPITAL RECOVERY	10.4	9.6	20.0		
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	37.1	3.5	40.6		
ANNUAL ENERGY AND POWER COSTS	5.0	1.0	6.0		
TOTAL ANNUAL COSTS	52.5	14.1	66.6		
COSTS ($)/METRIC TON OF PRODUCT*	0.10	0.027	0.127		

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm) RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL A	B	C	D	E
TSS	300,000	20	0	20		
As	0.6	0.5	0	0.5		
Cd	0.1	0.05	0	0.05		
Cu	0.5	0.05	0	0.05		
Mo	5	-	0	1.0		
Zn	0.2	0.2	0	0.1		

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: LIME PRECIPITATION
LEVEL B: TOTAL RECYCLE (ZERO DISCHARGE)
LEVEL C: LEVEL A PLUS (LEVEL B WITHOUT ZERO DISCHARGE)

Capital Investment:

Lime precipitation unit	$ 62,000
Contingency and contractor's fee	8,060
Total Capital Investment	$ 70,060

Annual Cost:

Amortization	$ 10,440
Operation and Maintenance (O&M)	
Operating personnel	$ 9,450
Equipment repair and maintenance	3,100
Materials	23,870
Insurance	700
Total O&M costs	$ 37,120
Electricity	5,020
Total Annual Cost	$ 52,580

Level B: Total Recycle (Zero Discharge)

Mills in this subcategory recycle approximately 60 percent of their process water. The remaining 40 percent (1,968 cubic meters, equivalent to 520,000 gallons, per day) is discharged Level-B technology requires additional pumps and piping to attain total recycle.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level B:

Piping - Flow @ 2 meters (6.6 feet)/second through pipe measuring 12 cm (5 in.) x 1,750 meters (5,740 feet)

Pumps - water pumps rated at 1,968 l (361 gal)/min

Operating-Cost Assumptions for Level B:

Power - 7.5 kW (10 hp)

Capital Investment:

Piping	$ 52,500

Pumps	4,300
Equipment subtotal	56,800
Contingency and contractor's fee	7,385
Total Capital Investment	$ 64,185
Annual Cost:	
Amortization	9,565
Operation and Maintenance (O&M)	
Equipment repair and maintenance	$ 2,840
Insurance	640
Total O&M costs	3,480
Electricity	1,000
Total Annual Cost	$ 14,045

Level C: Level A plus Level B

Level-C technology is applicable in areas where there is excess water. The total cost of attaining this level is the sum of the costs of attaining levels A and B. These costs are shown in Table VIII-18.

Ferroalloy Mills Annually Processing More Than 5,000 Metric Tons (5,500 Short Tons) Ore By Flotation

There are four mills in this subcategory, all of which are located in the western U.S. The range of ore milled is 7,200 to 15,480,000 metric tons (7,925 to 17,030,000 short tons) annually. The daily mill wastewater ranges from 30 to 94,600 cubic meters (7,925 to 25,000,000 gallons).

A hypothetical mill with an annual milling capacity of 5,600,000 metric tons (6,160,000 short tons) and with a daily wastewater flow of 22,710 cubic meters (6,000,000 gallons) is representative for this subcategory. Four levels of technology are considered. The total costs of achieving these levels are shown in Table VIII-19.

Waste Water Treatment/Control

TABLE VIII-19. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Ferroalloy Mills Annually Processing More Than 5,000 Metric Tons (5,512 Short Tons) Ore by Flotation

PLANT SIZE: 5,600,000 **METRIC TONS (**6,160,000 **SHORT TONS) PER YEAR OF** ore milled

PLANT AGE: N/A **YEARS** **PLANT LOCATION:** N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	126.6	113.0	252.1	269.7	
ANNUAL CAPITAL RECOVERY	18.9	16.8	36.1	39.7	
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	104.5	6.1	70.5	53.1	
ANNUAL ENERGY AND POWER COSTS	10.7	12.3	20.6	13.3	
TOTAL ANNUAL COSTS	134.1	35.2	127.2	106.1	
COSTS ($)/METRIC TON OF PRODUCT*	0.023	0.006	0.022	0.02	

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	500,000	20	0	20	20	
COD	135	50	0	25	25	
Cyanide	0.45	0.05	0	0.02	0.02	
As	0.6	0.5	0	0.5	0.5	
Cd	0.74	0.05	0	0.05	0.05	
Cu	51	0.05	0	0.05	0.05	
Mo	17	-	0	1.0	1.0	
Zn	50	0.2	0	0.1	0.1	

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: LIME PRECIPITATION AND DISCHARGE
LEVEL B: TOTAL RECYCLE
LEVEL C: LEVEL B PLUS FERRIC SULFATE ADDITION, FLOCCULATION, SETTLING, LIME NEUTRALIZATION, SECONDARY SETTLING, AND AERATION
LEVEL D: LEVEL B PLUS AERATION, SETTLING, AND ION EXCHANGE

Level A: Lime Precipitation and Discharge

The settling ponds necessary for adequate precipitation and settling are considered to be already installed. The addition of 1.36 kg of pebbled lime per 3785 liters (3.0 lb/1000 gallons) of water is necessary for precipitation.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Lime precipitation unit

Operating-Cost Assumptions for Level A:

Operating personnel - 3 hr/day x 360 days/year

Lime - pebbled, quantity of 2,857 metric tons (3,150 short tons)/year

Power - 75 kW (100 hp)

Capital Investment:

Equipment

Lime precipitation unit	$ 112,000
Contingency and contractor's fee	14,560
Total equipment cost	126,560
Total Capital Investment	$ 126,560

Annual Cost:

Amortization	$ 18,860

Operation and Maintenance (O&M)

Operating personnel	$ 9,450
Equipment repair and maintenance	5,600
Materials	88,200
Insurance	1,265
Total O&M costs	$ 104,515

Electricity	10,700

Total Annual Cost	$ 134,075

Level B: Total Recycle

To achieve total recycle, additional piping and pumps would be necessary. The implementation of a total-recycle system does not necessarily imply no discharge. The problem of excess water due to rainfall still exists. The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level B:

Pumps - water pumps rated at 15,770 l (4,163 gal)/min

Piping - Flow @ 2 meters (6.6 feet)/sec through pipe measuring 42 cm (16.5 in.) x 1000 meters (3,280 feet)

Operating-Cost Assumptions for Level B:

Power - 89 kW (120 hp)

Capital Investment:

Equipment

Piping	$ 21,000
Pumps	79,000
Equipment subtotal	100,000
Contingency and contractor's fee	13,000
Total Capital Investment	$ 113,000

Annual Cost:

Amortization	$ 16,840
Operation and Maintenance (O&M)	
Equipment repair and maintenance	$ 5,000
Insurance	1,130
Total O&M costs	6,130
Electricity	12,250
Total Annual Cost	$ 35,220

Level C: Level B plus Ferric Sulfate Addition, Flocculation, Settling, Lime Neutralization, Secondary Settling, and Aeration

Level-C technology may be applied in areas of excess water. It is assumed that 25 percent of the mill wastewater is bled and discharged--a daily total of 5,677 cubic meters (1,500,000 gallons). The treatment recommended for mills in this subcategory is the addition of 75 mg/l of ferric sulfate and 5 mg/l of flocculant to the wastewater stream. Acid is also added to lower the pH to 4.5; however, no cost is shown for this item, as the cost is negligible. The wastewater is then contained for one day in a settling pond. Prior to discharge, the wastewater is neutralized with lime (0.45 kg/3.785 cubic meters, equivalent to 1 lb/1,000 gallons) and contained in an aerated pond. Aeration is needed to lower COD and to convert cyanide to cyanate. The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level C:

2 Settling ponds - dike height of 3 m (10 ft)
top width of 3 m (10 ft)
capacity of 8,516 cubic meters (2,250,000 gal)

Land - 1.06 hectares (2.6 acres)

Ferric sulfate addition - 2 mix tanks with capacity of 14.2 cubic meters (3,750 gallons)
1 metering pump

Flocculation system

Lime neutralization system

Aerator - 18 kW (24 hp)

Piping - Flow @ 2 meters (6.6 feet)/sec through pipe measuring 21 cm (8.3 in.) x 200 meters (656 feet)

Operating-Cost Assumptions for Level C:

Operating personnel - 6 hr/day

Materials - lime @ 236 metric tons (260 short tons)/year

ferric sulfate @ 149 metric tons (163 short tons)/year
flocculant @ 9.9 metric tons (10.9 short tons)/year

Power - 60 kW (81 hp)

Capital Investment:

Facilities

Lagoons	$ 22,000
Contingency and contractor's fee	2,860
Total facility cost	$ 24,860

Land	1,860

Equipment

Ferric sulfate system	12,550
Flocculation system	14,900
Lime neutralization unit	55,000
Piping	9,000
Aeration equipment	8,000
Equipment subtotal	99,450
Contingency and contractor's fee	12,930
Total equipment cost	112,380
Total Capital Investment	$139,100

Annual Cost:

Amortization

Facility	$ 2,530
Equipment	16,750
Total amortization	$ 19,280

Operation and Maintenance (O&M)

Land	$ 185
Operating personnel	18,900
Facility repair and maintenance	660
Equipment repair and maintenance	4,975
Materials	38,235
Taxes	45
Insurance	1,390

Total O&M costs	$ 64,390
Electricity	8,270
Total Annual Cost	$ 91,940

Level D: Level B plus Aeration, Settling, and Ion Exchange

Level-D treatment is an alternative to level-C treatment. Level-D technology may be applied in areas of excess water. It is assumed that 10 percent of the mill wastewater is discharged (a total of 2,271 cubic meters, equivalent to 600,000 gallons). This level of treatment includes an aeration pond and an ion-exchange unit.

The excess wastewater is contained for one day in an aeration pond to lower COD from 100 mg/l to 20 mg/l and to convert cyanide to cyanate. The wastewater is then passed on to an ion-exchange unit for further treatment before discharge. The amount of ion-exchange resin actually needed would depend upon the characteristics of the wastewater. For the purposes of this report, it is assumed that 5.5 cubic meters (7.2 cubic yards) of resin would be adequate.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level D:

Settling pond - dike height of 3 m (10 ft)
top width of 3 m (10 ft)
capacity of 3,400 cubic meters
(898,200 gallons)

Land - 0.26 hectare (0.64 acre)

Aerator - 7.5 kW (10 hp)

Ion Exchanger - capacity of 5.5 cubic meters (7.1 cubic yards)

Piping - Flow @ 2 meters (6.6 feet)/sec through pipe
measuring 13 cm (5 in.) x 100 meters (328 feet)

Operating-Cost Assumptions for Level D:

Operating personnel - 10.8 hr/day

Resins - replacement every 3 years

Power - 7.5 kW (10 hp)

Capital Investment:	
Facilities	
Lagoon	$ 6,200
Contingency and contractor's fee	805
Total facility cost	$ 7,005
Land	455
Equipment	
Aeration unit	3,400
Ion exchanger	125,000
Piping	3,200
Equipment subtotal	$ 131,600
Contingency and contractor's fee	17,110
Total equipment cost	148,710
Total Capital Investment	$156,170
Annual Cost:	
Amortization	
Facility	$ 715
Equipment	22,165
Total amortization	$ 22,880
Operation and Maintenance (O&M)	
Land	$ 45
Operating personnel	34,020
Facility repair and maintenance	185
Equipment repair and maintenance	6,580
Materials	4,585
Taxes	10
Insurance	1,560
Total O&M costs	$ 46,985
Electricity	1,020
Total Annual Cost	$ 70,885

Ferroalloy Mills Practicing Ore Leaching

There is only one ferroalloy mill in this subcategory, and it is located in the southeastern U.S. The ore milled annually is 410,400 metric tons (451,500 short tons), with a daily wastewater discharge of 5,300 cubic meters (1,400,000 gallons).

There are four levels of technologies considered. The total costs of achieving these levels are shown in Table VIII-20.

Waste Water Treatment/Control

Level A: Lime Precipitation, Thickener, Sludge Pond, and Surge Pond

Because of the high buffering effects of salts in the wastewater the addition of 2.25 kg of pebbled lime per 3.785 cubic meters (5 lb/1000 gallons) of wastewater is required for precipitation. The capital and operating costs and assumptions for attaining this level are shown below.

Capital Cost Components and Assumptions for Level A:

Sludge pond - dike height 3 meters (10 ft)
top width of 3 meters (10 ft)
capacity of 10,000 cubic meters
(2,640,000 gal).

Surge pond - dike height 3 meters (10 ft)
top width of 3 meters (10 ft)
capacity of 7950 cubic meters
(2,100,000 gal)

Lime precipitation system

Land - 1.1 hectares (2.7 acres)

Piping - flow at 1 meter (3.3 feet)/sec through pipe
measuring 29 cm (11.5 in) x 1000 meters

Sludge pumps - rated at 370 liters (98 gallons)/min

Thickener - 1 hour retention; continuous flow
250 cubic meter capacity (66,050 gallons)

Operating Cost Assumptions for Level A:

Operating personnel - 4 hr/day

TABLE VIII-20. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Ferroalloy Mill Practicing Ore Leaching

PLANT SIZE: 410,400 METRIC TONS (451,500 SHORT TONS) PER YEAR OF ore milled

PLANT AGE: N/A YEARS PLANT LOCATION: N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	280.0	424.2	429.2	490.5	
ANNUAL CAPITAL RECOVERY	40.1	61.6	62.5	70.9	
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	61.7	384.9	385.1	388.3	
ANNUAL ENERGY AND POWER COSTS	5.7	16.7	16.7	29.3	
TOTAL ANNUAL COSTS	107.5	463.2	464.3	488.5	
COSTS/METRIC TON OF PRODUCT*	0.26	1.13	1.13	1.19	

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	300,000	20	20	20	20	
Ammonia	1200	1200	30	30	5	
As	0.6	0.5	0.5	0.5	0.5	
Cd	0.3	0.05	0.05	0.05	0.05	
Cr	1.1	1.1	1.1	0.05	0.05	
Cu	0.3	0.05	0.05	0.05	0.05	
Zn	4	0.2	0.2	0.1	0.1	

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: LIME PRECIPITATION, THICKENER, SLUDGE AND SURGE POND
LEVEL B: LEVEL A PLUS AMMONIA STRIPPING
LEVEL C: LEVEL B PLUS SULFUR DIOXIDE INJECTION
LEVEL D: LEVEL C PLUS AERATION

Lime - 1111 metric tons/year (1225 short tons)
Power - 57 hp

Capital Investment:

Facilities

Sludge and Surge pond	$ 24,500
Contingency and contractor's fee	3,200
Total facility cost	$ 27,700

Land

Land	1,925

Equipment

Lime precipitation system	$ 76,050
Thickener	85,000
Piping	56,000
Sludge	4,500
Equipment Subtotal	221,550
Contingency and Contractor's fee	28,800
Total equipment cost	250,350
Total Capital Investment	$ 279,975

Annual Cost:

Amortization

Facility	2,700
Equipment	37,300
Total amortization	$ 40,000

Operation and Maintenance (O&M)

Land	190
Operating personnel	12,600
Facility repair & maintenance	735
Equipment repair & maintenance	11,080
Materials	34,220
Taxes	50
Insurance	2,800
Total O&M costs	61,675

Electricity	5,700
Total Annual Cost	$ 107,445

Level B: Level A plus Ammonia Stripping

Level B technology suggests that 10 percent of the wastewater (530 cubic meters, equivalent to 140,000 gallons) be segregated from the rest of the mill wastewater. This water is contaminated with large amounts of ammonia. To remove the ammonia, the wastewater must first be treated with caustic soda to raise the pH to 11. The wastewater must then be sent to an air stripper, which will remove 90 to 95 percent of the ammonia.

The costs for ammonia stripping have been provided by surveyed operations. The capital and operating costs and assumptions for attaining this level are shown below.

Total costs for level B are shown in Table VIII-20.

Capital Cost Components and Assumptions for Ammonia Stripping

Piping - flow at 1 meter (3.3 ft) sec through pipe measuring 9 cm (3.5 in) x 1000 meters (3280 feet)

Pumps - slurry type, rated at 370 liters (98 gallons)/min

Ammonia stripper - packed column at $33,000
fan at $9,000

Caustic soda addition
- mix tank with capacity of 228 cubic meters (60,000 gallons)
- liquor feed pump with capacity of 945 liters/hour (250 gallons)
- instrumentation on mix tank for pH check/control

Operating Cost Assumptions for Ammonia Stripping

Operating personnel - 3 hour/shift, 3 shift/day

Caustic soda - 3500 metric tons (3880 short tons) at $82/metric ton ($74.38 short ton)

Power - 110 hp

Capital Investment:	
Equipment	
Caustic soda addition	$ 56,100
Ammonia stripper	42,000
Piping	25,000
Pumps	4,500
Equipment subtotal	$ 127,600
Contingency and Contractor's fee	16,590
Total Capital Investment	$ 144,190
Annual Cost	
Amortization	21,485
Operation and Maintenance (O&M)	
Operating personnel	$ 28,350
Equipment repair and maintenance	6,380
Materials	287,000
Insurance	1,440
Total O&M	$ 323,170
Electricity	$ 11,000
Total Annual Cost	$ 355,655

Level C: Level B plus Sulfur Dioxide Injection

Sulfur dioxide injection is required for chromium reduction. The sulfur dioxide injection system requires a holding tank, ejector, and sulfur dioxide. Total costs for Level C are shown in Table VIII-20. The incremental capital and operating costs and assumptions for attaining this level are shown below.

Capital Cost Components and Assumptions for Level C:

Sulfur dioxide injectin system - 1 holding tank with retention time of 5 minutes and a capacity of 18,400 liters (4,860 gallons)

Ejector

Operating Cost Assumptions for Level C:

Sulfur dioxide - amount needed is low and is presumed to be readily available.

Capital Investment:

Equipment

Ejector	$1,000
Sulfur dioxide injection tank	3,400
Equipment subtotal	4,400
Contingency and contractor's fee	570
Total Capital Investment	$ 4,970

Annual Cost:

Amortization	890

Operation and Maintenance (O&M)

Equipment repair and maintenance	220
Insurance	50
Total O&M	270
Total Annual Cost	$ 1,160

Level D: Level C plus Aeration

Further treatment would include the merging of the waste streams into an aerated pond. The purpose of aeration is to lower COD. A one-day retention is recommended before discharge.

The capital and operating costs and assumptions for attaining this level are shown below. Total costs for Level D are shown in Table VIII-20.

Capital Cost Components and Assumptions for Level D:

Pond - dike height of 3 meters (10 ft); top width of 3 meters; and capacity 7,950 cubic meters (2,100,000 gallons)

Land - 0.5 hectare (1.2 acres)

Aerator - 94 kW (126 hp)

Capital Investment:

Facilities

Pond	$ 11,500
Contingency and contractor's fee	1,495
Total facilties cost	$ 12,995
Land	875
Equipment	
Aerator	$ 42,000
Contingency and contractor's fee	5,460
Total equipment cost	47,460
Total Capital Investment	$ 61,330
Annual Cost:	
Amortization	
Facility	1,325
Equipment	7,075
Total amortization	$ 8,400
Operation and Maintenance (O&M)	
Land	90
Facility repair and maintenance	345
Equipment repair and maintenance	2,100
Taxes	20
Insurance	615
Total O&M cost	3,170
Electricity	12,600
Total Annual Cost	$ 24,170

WASTE WATER TREATMENT COSTS FOR MERCURY-ORE CATEGORY

Mercury-Ore Mines

The exact number of operating mercury mines is difficult to determine at present. One open-pit mine is currently considered active; however, it does not have a discharge and is closed seasonally.

Currently, existing market conditions have resulted in almost no activity from underground mercury mines. It is expected that, with a return to more favorable market conditions, some underground mines will again become active.

In anticipation of a rise in the market price of mercury, a hypothetical mine was chosen to represent this subcategory. The representative mine has an annual ore production of 27,210 metric tons (30,000 short tons) with a daily wastewater flow of 378.5 cubic meters (100,000 gallons).

One level of technology is considered. The total costs of achieving this level are shown in Table VIII-21.

MERCURY ORE MINES

Waste Water Treatment Control

Level A: Lime Precipitation, Settling and Discharge

The addition of 1.36 kg of hydrated lime per 3.785 cubic meters (3.0 lb/1000 gallons) to the wastewater is recommended for precipitation of metals.

A 15 day supply of hydrated lime (2,040 kg equivalent to 4,488 lbs) is stored as a slurry (0.9 kg/3.785 l, equivalent to 2 lb/1 gallon) in a mixing tank. A portion of the slurry is drawn off and mixed with the mine water in another mixing tank for 15 minutes, then is pumped into a settling pond.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital Cost Components and Assumptions for Level A:

2 Ponds - dike height 2m (7 feet); top width of 3 m (10 feet) and capacity of 570 cubic meters (150,600 gallons)

Land - 0.2 hectare (0.5 acre)

Lime precipitation system -

> slurry storage tank with capacity of 8,580 liters (2,265 gallons) and containing a 15-day supply of lime slurry.
>
> mix tank with retention time of 15 minutes and capacity of 3,975 liters (1,050 gallons), based on flow of 265 liters (70 gallons) per minute.
>
> Pump with capacity of 265 liters (70 gallons) per minute.

TABLE VIII-21. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE

SUBCATEGORY: Mercury-Ore Mines

PLANT SIZE: 27,210 METRIC TONS (30,000 SHORT TONS) PER YEAR OF ore mined

PLANT AGE: N/A YEARS PLANT LOCATION: N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	29.5	29.6			
ANNUAL CAPITAL RECOVERY	4.2	4.2			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	6.5	9.7			
ANNUAL ENERGY AND POWER COSTS	1.1	1.1			
TOTAL ANNUAL COSTS	11.8	15.0			
COSTS/METRIC TON OF PRODUCT*	0.43	0.55			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	25	20	20			
Hg	0.001	0.001	0.0005			
Ni	0.2	0.1	0.1			

*ORE MINED. TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: LIME PRECIPITATION AND DISCHARGE
LEVEL B: LEVEL A AND SULFIDE PRECIPITATION

Piping - flow at 2m (6.6 feet)/sec through pipe measuring 5 cm (2 inches) x 1,100 meters (3,608 feet)

Operating Cost Assumptions for Level A:

Lime - 47.5 metric tons (53 short tons)/year

Operating personnel - 1 hr/day

Power - 8.2 kw (11 hp)

Capital Investment:

Facilities	
Lagoons	$ 3,400
Contingency & Contractor's fee	440
Total Facility Cost	$ 3,840
Land	350
Equipment	
Lime precipitation	6,950
Piping	15,400
Equipment Subtotal	22,350
Contingency & Contractor's fee	2,905
Total equipment cost	25,255
Total Capital Investment	$ 29,445

Annual Cost

Amortization	
Facility	$ 390
Equipment	3,765
Total Amortization	$ 4,155
Operation and Maintenance (O&M)	
Land	35
Operating personnel	3,150
Facility repair & maintenance	100
Equipment repair and maintenance	1,115
Materials	1,855
Taxes	10

Insurance	295
Total O&M Costs	$ 6,560
Total Annual Cost	11,815

Level B: Level A, Sulfide Precipitation and Discharge

Level B technology consists of level A plus sulfide precipitation. The addition of 1 mg sodium sulfide to one liter of wastewater (1 ppm) is recommended for precipitation.

The capital and operating costs for sulfide precipitation are shown below. Total costs for level B are shown in Table VIII-21.

Capital Cost Components and Assumptions for Sulfide Precipitation:

Precipitation:

Sulfide precipitation system - drum with capacity of 208 liters (55 gal)

Operating Cost Assumptions for Sulfide Precipitation.

Sodium sulfide - 132 kg (291 lb)/year

Operating personnel 1 hr/day

Capital Investment:

Equipment	
Sulfide precipitation unit	$ 100
Contingency and contractor's fee	15
Total Capital Investment	$ 115

Annual Cost:

Amortization	$ 15
Operation and Maintenance (O&M)	
Operating personnel	$3,150
Equipment repair & maintenance	5
Materials	30

Total O&M Cost	$3,185
Total Annual Cost	$3,200

Mercury Mills Employing Flotation Process

There are no mills currently operating in this subcategory. A mill utilizing a flotation process is due to open in 1975. This mill was chosen to be representative for this subcategory. It is expected to mill 159,000 metric tons (175,000 short tons) a year. Discharge of wastewater is expected to be 7,570 cubic meters (2,000,000 gallons) daily.

The recommended level of treatment is zero discharge of wastewater. Two alternatives for achieving zero discharge are considered. They are total recycle, or impoundment and evaporation. The costs of implementing these alternatives are shown in Table VIII-22.

Waste Water Treatment/Control

Level A: Total Recycle (Zero Discharge)

The facilities required to achieve total recycle include a rectangular pond of 40 hectares (100 acres) whose length is equal to twice its width. The pond would also require one transverse dike to provide two separate ponds, each having an area of 20 hectares (50 acres). The first pond would be used for sedimentation of suspended solids. The second pond would be used as a polishing pond. Water in the polishing pond would be recycled back to the mill.

Diversion ditching along one length and one width is recommended to avoid stress in the system due to seasonal runoff.

Additional equipment includes a tailing-disposal system and decant pumps and pipes. The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Pond - dike height of 2 m (7 ft)
top width of 3 m (10 ft)
capacity of 750,000 cubic meters

Land - 40 hectares (100 acres)

Transverse dike - height of 461 meters (1,512 feet)

TABLE VIII-22. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Mercury Mills Employing Flotation Process

PLANT SIZE: 159,000 METRIC TONS (175,000 SHORT TONS) PER YEAR OF ore milled

PLANT AGE: ___ YEARS PLANT LOCATION: Nevada

(under construction in 1975)

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	565.3	736.0			
ANNUAL CAPITAL RECOVERY	64.4	71.5			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	62.7	66.4			
ANNUAL ENERGY AND POWER COSTS	6.5	2.5			
TOTAL ANNUAL COSTS	133.6	140.4			
COSTS ($)/METRIC TON OF PRODUCT*	0.84	0.88			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	250,000	0	0			
Hg	0.0072	0	0			
Ni	0.05	0	0			

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.90.

LEVEL A: TOTAL RECYCLE (ZERO DISCHARGE)

LEVEL B: IMPOUNDMENT AND EVAPORATION (ZERO DISCHARGE)

Diversion ditching - total of 1,405 meters (4,608 feet)

Distribution system - around one pond - pipe measuring 34 cm (13.4 in.) x 1,844 m (6,048 ft)

Piping - mill to pond - flow @ 1 m (3.3 ft)/sec through pipe measuring 34 cm (13.4 in.) x 1000 meters (3,280 feet)

pond to mill - flow @ 2 m (6.6 feet)/sec through pipe measuring 25 cm (9.8 in.) x 1000 meters (3,280 feet)

Pumps - mill to pond - slurry type, capacity of 5,260 l (1,389 gal)/minute
pond to mill - water type, capacity of 5,260 l (1,389 gal)/minute

Operating-Cost Assumptions for Level A:

Power - 48 kW (65 hp)

Capital Investment:

Facilities

Diversion ditching	$ 2,320
Lagoon	149,760
Transverse dike	24,900
Facility subtotal	176,980
Contingency and contractor's fee	23,010
Total facility cost	$ 199,990
Land	70,000
Equipment	
Distribution system	119,860
Piping	116,000
Pumps	25,500
Equipment subtotal	261,360
Contingencity and contractor's fee	33,975
Total equipment cost	295,335
Total Capital Investment	$ 565,325

Annual Cost:

Amortization

Facility	$ 20,370
Equipment	44,015
Total amortization	$ 64,385

Operation and Maintenance (O&M)

Land	7,000
Facility repair and maintenance	5,310
Equipment repair and maintenance	7,075
Distribution system maintenance	35,960
Taxes	1,750
Insurance	5,650
Total O&M costs	62,745

Electricity	6,500
Total Annual Cost	$ 133,630

Level B: Impoundment and Evaporation (Zero Discharge)

The facilities required for level-B treatment are essentially the same as those required for level-A treatment. However, a larger pond area is required. An 80-hectare (200-acre) rectangular pond with three transverse dikes to provide four separate ponds of 20 hectares (50 acres) each is required for impoundment and evaporation.

The equipment required includes a tailing-disposal system (the same as that for level A), pumps, and pipes. The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level B:

Pond - dike height of 2 meters (7 ft)
top width of 3 meters (10 ft)
capacity of 1,500,000 cubic meters (396,260,000 gal)

Land - 80 hectares (200 acres)

Transverse dikes - 3, each 650 meters (2,132 feet) in length

Diversion ditching - around one length and one width, 1,970 meters (6,462 feet) in length

Distribution system - piping around one 20-hectare (50-acre) pond; diameter of 34 cm (13.4 in.)

and length of 1,844 m (6,048 ft)

Piping - mill to pond flow @ 1 m (3.3 ft)/sec through pipe measuring 34 cm (13.4 in.) x 1000 meters (3,280 feet)

Pumps - mill to pond slurry type, capacity of 5,260 l (1,390,000 gal)/min

Operating-Cost Assumptions for Level B:

Power - 19 kW (25 hp)

Capital Investment:

Facilities	
Diversion ditching	$ 3,250
Lagoon	211,200
Transverse dike	105,300
Facility subtotal	319,750
Contingency and contractor's fee	41,570
Total facility cost	$ 361,320
Land	140,000
Equipment	
Distribution system	126,750
Piping	65,000
Pumps	16,000
Equipment subtotal	207,750
Contingency and contractor's fee	27,010
Total equipment cost	234,760
Total Capital Investment	$ 736,080

Annual Cost:

Amortization	
Facility	$ 36,800
Equipment	34,745
Total amortization	$ 71,545
Operation and Maintenance (O&M)	
Land	14,000
Facility repair and maintenace	9,590

Equipment repair and maintenance	4,050
Distribution system maintenance	38,025
Taxes	3,500
Insurance	7,275
Total O&M costs	66,[illegible]
Electricity	2,500
Total Annual Cost	$ 140,485

Mercury Mills Employing Gravity Separation

There is only one mill in this subcategory. The discharge of wastewater is 1,665 cubic meters (436,000 gallons) a day during wet seasons. The mill process water is recycled. Annual ore milled is 27,000 metric tons (30,000 short tons).

One level of technology is considered. The total costs of implementing this level are shown in Table VIII-23.

Waste Water Treatment Control

Level A: Diversion Ditching (Zero Discharge)

Diversion ditching along one length and one width of the present tailing pond is recommended to avoid stress in the system due to seasonal runoff. The capital costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Diversion ditching - 225 meters (738 feet) @ $1.65/meter ($0.50/foot)

Capital Investment:

Facilities

Diversion ditching	$	370
Facility subtotal		370
Contingency and contractor's fee		50
Total facility cost	$	420

TABLE VIII-23. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Mercury Mills Employing Gravity Separation

PLANT SIZE: 27,000 **METRIC TONS (** 30,000 **SHORT TONS) PER YEAR OF** ore milled

PLANT AGE: 4 **YEARS** **PLANT LOCATION:** California

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	0.4				
ANNUAL CAPITAL RECOVERY	0.045				
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	0.010				
ANNUAL ENERGY AND POWER COSTS	-				
TOTAL ANNUAL COSTS	0.055				
COSTS($)/METRIC TON OF PRODUCT*	0.002				

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	154,000	0				
Hg	0.68	0				
Ni	0.125	0				

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: DIVERSION DITCHING (ZERO DISCHARGE)

Total Capital Investment	$	420
Annual Cost:		
Amortization	$	45
Operation and Maintenance (O&M)		
Facility repair and maintenance	$	10
Total O&M costs		10
Total Annual Cost	$	55

WASTEWATER TREATMENT COSTS FOR URANIUM ORE CATEGORY

Uranium Mines

There are between 120 and 175 uranium mines in the U.S. The annual amount of ore mined ranges from 1,800 to 504,000 metric tons (1,980 to 554,500 short tons). The daily wastewater flow ranges from 0 to 5,000 cubic meters (0 to 1,321,000 gallons).

A hypothetical mine with an annual ore production of 280,000 metric tons (308,000 short tons) and with a daily water flow rate of 1,900 cubic meters (500,000 gallons) was chosen as representative.

Several levels of technology have been considered. The total costs of implementing these levels are shown in Table VIII-24.

Waste Water Treatment Control

Level A: Flocculation

The necessary settling and polishing ponds are already installed at the typical uranium mining operation. The addition of 5 mg/l of flocculant is required for settling of suspended solids. The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

Flocculation -

TABLE VIII-24. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE (Sheet 1 of 2)

SUBCATEGORY: Uranium Mines

PLANT SIZE: 280,000 METRIC TONS (308,000 SHORT TONS) PER YEAR OF ore mined

PLANT AGE: N/A YEARS PLANT LOCATION: N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	16.8	86.8	228.1	240.5	282.6
ANNUAL CAPITAL RECOVERY	2.5	12.9	33.9	35.8	42.1
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	11.4	15.2	(45.2)**	(19.9)**	(2.0)**
ANNUAL ENERGY AND POWER COSTS	11.3	11.5	11.5	11.5	13.5
TOTAL ANNUAL COSTS	25.2	39.6	0.2	27.4	53.6
COSTS/METRIC TON OF PRODUCT*	0.09	0.14	nil	0.10	0.19

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	530	50	20	20	20	20
COD	750	200	100	100	100	100
As	2	2	2	2	0.5	0.5
Cd	0.05	0.05	0.05	0.05	0.05	0.05
Mo	16	16	16	16	16	16
V††	10	10	10	10	10	10
Zn	0.5	0.5	0.5	0.5	0.5	0.5
Ra 226	3,200†	200†	30†	30†	3†	3†
U	25	25	25	2	2	2

*ORE MINED. TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

**TREATMENT RESULTS IN NET RETURN ON INVESTMENT. (REFER TO TEXT)

†VALUE IN PICOCURIES/ℓ

LEVEL A: FLOCCULATION
LEVEL B: LEVEL A PLUS CLARIFICATION
LEVEL C: LEVEL B PLUS ION EXCHANGE
LEVEL D: LEVEL C PLUS BARIUM CHLORIDE COPRECIPITATION
LEVEL E: LEVEL D PLUS LIME PRECIPITATION

††HYPOTHETICAL

TABLE VIII-24. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE (Sheet 2 of 2)

SUBCATEGORY: Uranium Mines

PLANT SIZE: 280,000 METRIC TONS (308,000 SHORT TONS) PER YEAR OF ore mined

PLANT AGE: N/A YEARS PLANT LOCATION: N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	E	F	G	H	
TOTAL INVESTED CAPITAL	282.6	294.0	435.3	298.2	
ANNUAL CAPITAL RECOVERY	42.1	43.8	64.8	44.4	
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	(2.0)**	2.2	8.9	49.7	
ANNUAL ENERGY AND POWER COSTS	13.5	16.5	16.5	16.5	
TOTAL ANNUAL COSTS	53.6	62.5	90.2	110.6	
COSTS/METRIC TON OF PRODUCT*	0.19	0.223	0.32	0.395	

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		E	F	G	H	
TSS	530	20	20	20	20	
COD	750	100	50	50	50	
As	2	0.5	0.5	0.5	0.5	
Cd	0.05	0.05	0.05	0.05	0.05	
Mo	16	16	16	2.0	2.0	
V	10	10	10	10	5	
Zn	0.5	0.5	0.1	0.1	0.1	
Ra 226(dissolved)	3,200†	3†	3†	3†	3†	
U	25	2	2	2	2	

*ORE MINED. TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

**TREATMENT RESULTS IN NET RETURN ON INVESTMENT. (REFER TO TEXT)

†VALUE IN PICOCURIES/ℓ
LEVEL F: LEVEL E PLUS SULFIDE PRECIPITATION AND AERATION
LEVEL G: LEVEL F PLUS ION EXCHANGE
LEVEL H: LEVEL F PLUS $FeSO_4$ COPRECIPITATION

1 mix tank with capacity of 1,900 liters (500 gallons)
2 mix tanks with capacity of 9,500 liters (2,500 gallons)
2 positive-displacement pumps

Operating-Cost Assumptions for Level A:

Flocculant - 6,621 kg (7,300 lb)/year

Operating personnel - 1 hr/day

Power - 9.7 kW (13 hp)

Capital Investment:

Equipment

Flocculation system	$ 14,900
Contingency and contractor's fee	1,940
Total Capital Investment	$ 16,840

Annual Cost:

Amortization	$ 2,510
Operation and Maintenance (O&M)	
Operating personnel	$ 3,150
Equipment repair and maintenance	745
Materials	7,300
Insurance	170
Total O&M costs	11,365
Electricity	11,300
Total Annual Cost	$ 25,175

Level B: Level A plus Clarification

Level-B technology includes level-A technology plus clarification. A one-hour retention time in the clarification unit is assumed. The clarifier required has a capacity of 80 cubic meters (20,850 gallons). The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level B:

Clarifier - capacity of 80 cubic meters (20,850 gallons)

Operating-Cost Assumptions for Level B:

Power - 1.5 kW (2 hp)

Capital Investment:

Equipment

Clarifier	$ 62,000
Contingency and contractor's fee	8,060
Total Capital Investment	$ 70,060

Annual Cost:

Amortization	$ 10,440
Operation and Maintenance (O&M)	
Equipment repair and maintenance	$ 3,100
Insurance	700
Total O&M costs	3,800
Electricity	200
Total Annual Cost	$ 14,440

Level C: Level B plus Ion Exchange

The amount of resin needed is dependent upon the characteristics of the wastewater. For this report, the amount of resin chosen was based on actual operations.

A recovery of 13.6 kg (30 lb) of U_3O_8 is made daily in the ion-exchange unit.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level C:

Ion exchanger - capacity of 5.6 cubic meters (7.3 cubic yards)

Operating-Cost Assumptions for Level C:

Operating personnel - 3.5 hr/day

Materials - change resins every 3 years

Product recovery - 13.6 kg (30 lb)/day of U_3O_8 @ $17.60/kg ($7.99/lb)

Capital Investment:

Equipment

Ion exchanger	$ 125,000
Contingency and contractor's fee	16,250
Total Capital Investment	$ 141,250

Annual Cost:

Amortization	$ 20,975

Operation and Maintenance (O&M)

Operating personnel	$ 11,025
Equipment repair and maintenance	6,250
Materials	4,670
Insurance	1,410
Total O&M costs	23,355
Total Annual Cost	44,330
Less Product Recovery	83,775
Net Annual Recovery	$ 39,445

Level D: Level C plus Barium Chloride Coprecipitation

Level-D technology, compared with that of level C, requires the addition of flocculant and barium chloride for the precipitation of radium. The costs for this system are based on actual operations. The costs for barium chloride coprecipitation are shown below. Total costs for level D are shown in Table VIII-24.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level D:

Barium chloride coprecipitation system

Operating-Cost Assumptions for Level D:

Flocculant - 6.4 metric tons (7 short tons)/year

Barium chloride - 5.4 metric tons (6 short tons)/year
@ $805/metric ton ($730/short ton)

Operating personnel - 2 hr/day

Capital Investment:

Equipment

Barium chloride coprecipitation system	$ 11,000
Contingency and contractor's fee	1,430
Total Capital Investment	$ 12,430

Annual Cost:

Amortization	$ 1,850

Operation and Maintenance (O&M)

Operating personnel	$ 6,300
Equipment repair and maintenance	550
Materials	18,345
Insurance	125
Total O&M costs	$ 25,320
Total Annual Cost	$ 27,170

Level E: Level D plus Lime Precipitation

The required settling ponds are currently available for precipitation. The addition of 0.9 kg of hydrated lime per 3.785 cubic meters (2 lb/1000 gal) of wastewater is considered sufficient for precipitation of heavy metals. The total costs for implementing level-E technology are shown in Table VIII-24.

The incremental capital and operating costs and assumptions for the lime precipitation necessary to attain this level are shown below.

Capital-Cost Components and Assumptions for Level E:

Lime precipitation system

Operating-Cost Assumptions for Level E:

Lime - 160 metric tons (175 short tons)/year

Operating personnel - 3 hr/day

Power - 14.9 kW (20 hp)

Capital Investment:

Equipment

Lime precipitation system	$ 37,250
Contingency and contractor's fee	4,845
Total Capital Investment	$ 42,095

Annual Cost:

Amortization	$ 6,275

Operation and Maintenance (O&M)

Operating personnel	$ 9,450
Equipment repair and maintenance	1,865
Materials	6,125
Insurance	420
Total O&M costs	$ 17,860

Electricity	$ 2,000
Total Annual Cost	$ 26,135

Level F: Level E plus Sulfide Precipitation and Aeration

To achieve level F, the addition of 3 mg/l of sodium sulfide and aeration to lower COD levels would be necessary. The total costs for implementing level-F technology are shown in Table VIII-24.

The incremental capital and operating costs and assumptions for attaining this level via sulfide precipitation and aeration are shown below.

Capital-Cost Components and Assumptions for Level F:

Sulfide precipitation system

Aeration - 30 kg (66 lb) of oxygen/hour

Operating-Cost Assumptions for Level F:

Sodium sulfide - 1,985 kg (4,375 lb)/year

Power - 22.4 kW (30 hp)

Operating personnel - 1 hr/day

Capital Investment:

Equipment

Sulfide precipitation unit	$ 100
Aeration equipment	10,000
Equipment subtotal	10,100
Contingency and contractor's fee	1,315
Total Capital Investment	$ 11,415

Annual Cost:

Amortization	$ 1,700
Operation and Maintenance (O&M)	
Operating personnel	$ 3,150
Equipment repair and maintenance	505
Materials	440
Insurance	115
Total O&M costs	4,210
Electricity	3,000
Total Annual Cost	$ 8,910

Level G: Level F plus Ion Exchange

For further removal and recovery of molybdenum, another ion-exchange unit would be necessary. Approximately the same amount of Mo is recovered as uranium. The incremental costs for this system are the same as for level C. However, the value of the recovered Mo differs. The incremental capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level G:

Ion exchanger - capacity of 5.6 cubic meters (7.3 cubic yards)

Operating-Cost Assumptions for Level G:

Operating personnel - 3.5 hr/day

Material - change resins every 3 years

Product recovery - 4.0 kg (9 lb)/day of Mo @ \$3.50/kg (\$1.59/lb)

Capital Investment:

Equipment

Ion exchanger	\$ 125,000
Contingency and contractor's fee	16,250
Total Capital Investment	\$ 141,250

Annual Cost:

Amortization	\$ 20,975

Operation and Maintenance (O&M)

Operating personnel	\$ 11,025
Equipment repair and maintenance	6,250
Materials	4,670
Insurance	1,410
Total O&M costs	\$ 23,355
Total annual cost	44,330
Less product recovery	4,900
Total Annual Cost	\$ 39,430

Level H: Level F plus Ferrous Sulfate Coprecipitation

Ferrous sulfate is injected for the coprecipitation of vanadium and molybdenum.

Capital-Cost Assumptions for Level H:

$FeSO_4$ injector - Screw-type feeder

Operating-Cost Assumptions for Level H:

Material:
$FeSO_4$ - 1,035 metric tons (1,139 short tons) per year
Operating Personnel - 2 hr/day
Power - 0.75 kW (1hp)

Capital Investment

Equipment

$FeSO_4$ system	$ 3,750
Contingency and contractor's fee	490
Total Capital Investment	$ 4,240

Annual Cost

Amortization	$ 630

Operation and Maintenance (O&M)

Operating personnel	$ 6,570
Equipment repair and maintenance	190
Materials	40,685
Insurance	40
Total O&M	47,485

Electricity

Total Annual Cost	$48,210

Uranium Mills Using Acid or Alkaline Leaching

There are 20 mills in this subcategory. The annual amount of ore milled ranges from 143,640 to 2,295,000 metric tons (158,000 to 2,524,500 short tons). The daily wastewater flow ranges from 865 to 10,945 cubic meters (228,500 to 2,900,000 gallons). There are two operations in this subcategory that are known to be discharging (one acid and one alkaline leach). All others are at zero discharge.

The typical mill selected for costing has a capacity for handling 1,500 metric tons (1,650 short tons) of ore daily. The wastewater flow is 1.25 m^3 per metric ton of ore milled (330 gallons/short ton).

Four levels of technology are considered. The costs are shown in Table VIII-25.

Wastewater Treatment and Control

TABLE VIII-25. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Uranium Mills Using Acid, Alkaline, or Acid/Alkaline Leaching

PLANT SIZE: 547,500 METRIC TONS (602,250 SHORT TONS) PER YEAR OF ore milled

PLANT AGE: - YEARS PLANT LOCATION: Western U.S.

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY[1]	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	93.4	170.0	176.7	503.2	1275.0
ANNUAL CAPITAL RECOVERY	13.9	24.4	25.4	72.2	111.5
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	173.7	184.3	231.4	391.9	155.7
ANNUAL ENERGY AND POWER COSTS	4.5	16.3	16.4	102.7	4.8
TOTAL ANNUAL COSTS	192.1	225.0	273.2	566.8	272.0
COSTS/METRIC TON OF PRODUCT* ($)	0.35	0.41	0.50	1.04	0.50

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/l)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	500,000	20	20	20	-	0
COD	1,000	1,000	500	500	-	0
Ammonia	1,400	1,400	100	100	50	0
As	2.5	0.5	0.5	< 0.5	-	0
Mo	16	16	16	2	-	0
V	120	120	120	< 5	-	0
Zn	3	0.3	0.3	0.1	-	0
Ra 226 (diss)†	5-500	3	3	3	-	0
Ra 226 (total)†	15-500	10	10	10	-	0

* TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

(1) COSTS ARE EXPRESSED FOR TYPICAL ACID LEACHING MILL

LEVEL A: LIME PRECIPITATION ($BaCl_2$ TREATMENT ALREADY IN PLACE)
LEVEL B: LEVEL A PLUS SETTLING AND AERATION
LEVEL C: LEVEL B PLUS SODIUM SULFIDE TREATMENT AND $FeSO_4$ COPRECIPITATION
LEVEL D: STEAM STRIPPING PLUS LEVEL C
LEVEL E: ZERO DISCHARGE (UNLINED, TOTAL COSTS)

†PICOCURIES/LITER

Level A: Lime Precipitation

Hydrated lime is added at the main tailings pond to create alkaline conditions for heavy metal removal and neutralization of acidity. Hydrated lime is added to the tailings pond decant to effect precipitation of heavy metals by raising the pH from approximately neutral to pH 9. A barium chloride treatment system for removal of radium 226 is assumed to be already in operation at the discharging mills.

Capital-Cost Components and Assumptions for Level A:

Lime precipitation unit-	One hydrated lime system is employed. Lime slurry is pumped to tailings pond decant.

Operating-Cost Assumptions for Level A:

Material: Hydrated lime - 4,125 metric tons (4,538 short tons) per year. Operating personnel - 3 hr/day.
Power - 34.3 kW (46 hp)

Capital Investment:

Equipment

Lime precipitation system	$77,050
Pumps and piping	5,600
Contingency and contractor's fee	10,745
Total Capital Investment	$93,395

Annual Cost:

Amortization

$ 13,915

Operation and Maintenance (O&M)

Operating personnel	$ 9,855
Equipment repair and maintenance	4,135
Materials	158,815
Insurance	935
Total O&M	$173,740

Electricity

Total Annual Cost	$192,105

Level B: Settling and Aeration

Level B consists of settling and aeration to lower the COD level.

Capital Cost Components and Assumptions for Level B:

Settling pond - depth of 2 m (7 ft)
dike top width of 3 m (10 ft)
capacity of 3,370 cubic meters (890,400 gallons)
Aeration pond - Equipped with 8 mechanical aerators
depth of 2 m (7 ft)
dike top width of 3 m (10 ft)
capacity of 6,730 cubic meters (1,778,100 gallons)
Land - 0.89 hectare

Operating-Cost Assumptions for Level B:

Operating personnel - 2 hr/day
Power - 91 kW (122 hp)

Capital Investment:

Facilities

Settling pond	$ 5,600
Aeration pond	7,200
Contingency and contractor's fee	1,665
Total Facility Cost	$ 14,465
Land	$ 1,560

Equipment

Aerators	$ 46,355
Pumps and piping	7,215
Contingency and contractor's fee	6,965
Total equipment cost	$ 60,535
Total Capital Investment	$ 76,560

Annual Cost

Amortization

Facilities	$ 1,475
Equipment	9,020
Total Amortization	$ 10,495

Operation and Maintenance

Land	$ 155
Operating personnel	6,570
Facility repair and maintenance	385
Equipment repair and maintenance	2,680
Taxes	40
Insurance	765
Total O&M	$ 10,595

Electricity	$ 11,805
Total Annual Cost	$ 32,895

Level C: Addition of Ferrous Sulfate and Sulfide Precipitation

Ferrous sulfate is injected at the mill discharge for the coprecipitation of vanadium and molybdenum as ferric vanadate and ferric molybdate. Sodium sulfide is added at the settling pond to further suppress heavy metal concentration.

Capital-Cost Components and Assumptions for Level C:

$FeSO_4$ injector - screw-type feeder
Na_2S^* precipitation system - mixing tank plus chemical metering pump

Operating-Cost Assumptions for Level C:

Material:
  $FeSO_4$ - 1,022 metric tons (1,124 short tons) per year
  Na_2S^* - 3.65 metric tons (4 short tons) per year
Operating personnel - 2 hr/day
Power - 0.75 kW (1 hp)

Capital Investment:

Equipment

$FeSO_4$ system	$ 3,570
Na_2S^* system	2,430
Contingency and contractor's fee	780

Total Capital Investment	$ 6,780
Annual Cost	
Amortization	$ 1,010
Operation and Maintenance (O&M)	
Operating personnel	$ 6,570
Equipment repair and maintenance	300
Materials	40,150
Insurance	70
Total O&M	$ 47,090
Electricity	$ 95
Total Annual Cost	$ 48,195

Level D: Ammonia Steam Stripping

Mills which use ammonia in their extraction process may be required by state and local regulations to install ammonia removal systems. Such regulations could apply to both discharging and zero-discharge mills. Estimated capital and annual costs of a system capable of treating a daily flow of 190 cubic meters (719,150 gallons) of wastewater are summarized below. The treatment process results in the recovery of about 1,330 metric tons (1,460 short tons) of NH_3 annually. The recovered NH_3 could be used in the extraction process and its value offset against the annual system cost.

Capital Investment	
Facilities	
Concrete pits and building	$ 34,000
Contingency and contractor's fee	4,420
Total facility cost	$ 38,420
Land	715
Equipment	
Tray tower, steam plant, other	$254,285
Contingency and contractor's fee	33,055
Total equipment cost	$287,340
Total Capital Investment	$326,475

Annual Cost

Amortization	$ 46,735
Operation and Maintenance	160,460
Energy	86,365
Total Annual Cost	$293,560

Discussion

State regulations may require the installation of liners in tailings and settling ponds in some regions. The implementation of such regulations would force affected mills to construct new facilities. To assess the cost impact of such regulations, total wastewater treatment costs have been estimated for acid and alkaline discharging and zero-discharge mills. These total costs are presented in Table VIII-26 and include all treatment processes applicable at each treatment level. For example, the capital and annual costs associated with barium chloride addition are part of the Level-A costs in Table VIII-25. Note that the costs of this treatment process were excluded from the incremental costs presented in the preceding section, since this process was assumed extant at the operating mills.

Level-A capital costs can be categorized into four groups. The smallest capital costs, $556,000 and $592,000 are incurred by the discharging, unlined, alkaline and acid mills, respectively. Next in cost at $1,275,000 are zero-discharge, unlined acid and alkaline mills. Discharging lined acid and alkaline mills require a capital expenditure of about $1,900,000. The capital costs for zero-discharge, lined, acid and alkaline mills exceed $8,000,000.

The zero-discharge, unlined, acid and alkaline mills exhibit the lowest annual cost ($272,000) and treatment cost per metric ton of product ($0.50). Next, in order of increasing annual costs are the discharging, unlined, acid and alkaline mills. The zero-discharge, lined, acid and alkaline mills incur the highest annual costs. The magnitude of these costs is attributable mainly to the amortization costs of pond liners.

The costs of Level-B treatment affect only the discharging mills. The additional capital and annual costs are about $76,000 and $32,000 for unlined mills; $111,000 and $49,000 for the lined mills.

TABLE VIII-26. COMPARISON OF MODEL-MILL TOTAL EFFLUENT-TREATMENT COSTS

TYPE OF MILL	CUMULATIVE COSTS TO ATTAIN											
	Level A			Level B			Level C			Level D		
	Capital*	Annual*	$/MT†	Capital*	Annual*	$/MT†	Capital*	Annual*	$/MT†	Capital*	Annual*	$/MT†
1. Discharging, unlined, acid	$ 592	$ 389	$0.71	$ 669	$422	$0.77	$ 676	$470	$0.86	$1002	$ 764	$1.40
2. Discharging, lined, acid	1910	589	1.08	2022	637	1.16	2028	686	1.25	2355	979	1.79
3. Discharging, unlined, alkaline	556	381	0.70	633	413	0.75	640	462	0.84	966	755	1.38
4. Discharging, lined, alkaline	1874	580	1.06	1985	628	1.15	1992	677	1.24	2318	970	1.77
5. Zero-discharge, unlined, acid or alkaline	1275	272	0.50	0	0	0.50	0	0	0.50	1602	566	1.03
6. Zero-discharge, lined, acid	8023	1208	2.21	0	0	2.21	0	0	2.21	8350	1502	2.74
7. Zero-discharge, lined, alkaline	8024	1209	2.21	0	0	2.21	0	0	2.21	8350	1502	2.74

*Capital and annual costs are expressed in thousands of dollars.

†Costs (in dollars) per metric ton; to obtain cost per short ton, multiply each cost shown by 0.907.

Level-C treatment also applies only to the discharging mills. Level-C capital costs are small, less than $7,000. The annual costs amount to about $48,000 and represent primarily material costs.

Level D represents ammonia stripping and is estimated to be required by one-half of the operating mills.

Finally, it is noted that the relative capital and annual cost rankings of the model mills remain the same at each treatment level.

WASTE WATER TREATMENT COSTS FOR METAL ORES, NOT ELSEWHERE CLASSIFIED

Antimony Mines

There is only one mine in this subcategory. To date, it has no discharge; however, this mine was started in 1970, and a discharge may occur as it becomes more extensively developed.

A hypothetical discharge of 378.5 cubic meters (100,000 gallons) of wastewater daily is assumed for this operation. The annual ore production is 10,300 metric tons (11,365 short tons).

Two levels of technology are considered. The total cost of each level is shown in Table VIII-27.

Waste Water Treatment Control

Level A: Lime Precipitation and Settling

A simplified method of lime precipitation is considered. The addition of 1.36 kg of hydrated lime per 3.785 cubic meters (3 lb/1000 gallons) of wastewater is the recommended dosage. A 15-day supply of lime slurry is drawn off as needed, mixed with the raw wastewater for 15 minutes in a mix tank, and discharged to a settling pond for a one-day retention time. A secondary pond is needed for further settling before discharge.

The capital and operating costs and assumptions for attaining level A are shown below.

Capital-Cost Components and Assumptions for Level A:

TABLE VIII-27. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE

SUBCATEGORY: Antimony Mines

PLANT SIZE: 10,300 METRIC TONS (11,365 SHORT TONS) PER YEAR OF ore mined

PLANT AGE: N/A YEARS PLANT LOCATION: N/A

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	29.9	30.0			
ANNUAL CAPITAL RECOVERY	4.2	4.2			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	12.9	16.1			
ANNUAL ENERGY AND POWER COSTS	1.1	1.1			
TOTAL ANNUAL COSTS	18.2	21.4			
COSTS($)/METRIC TON OF PRODUCT*	1.77	2.08			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	25	20	20			
As	0.7	0.5	0.5			
Fe	1.5	1.0	1.0			
Sb	0.6	0.5	0.5			
Zn	0.3†	0.2	0.2			

*ORE MINED. TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: LIME PRECIPITATION AND SETTLING
LEVEL B: LEVEL A PLUS SULFIDE PRECIPITATION

† HYPOTHETICAL

2 Ponds - dike height of 2 meters (7 feet)
- top width of 3 meters (10 feet)
- capacity of 570 cubic meters (150,600 gallons)

Lime precipitation unit -

one mix tank with capacity of 8,515 liters (2,245 gallons)
one mix tank with capacity of 4,165 liters (1,102 gallons)

Pump - capacity of 0.26 cubic meter (69 gallons) per minute

Piping - mine to pond - Flow @ 2 meters (6.6 feet)/second through pipe measuring 5 cm (2 in.) x 1000 meters (3,280 ft)

pond A to pond B - Flow @ 1 meter (3.3 feet)/second through pipe measuring 7 cm (2.75 in.) x 100 meters (328 feet)

Land - 0.21 hectare (0.5 acre)

Operating-Cost Assumptions for Level A:

Lime - 47.25 metric tons (52.5 short tons)/year

Operating personnel - 3 hr/day

Power - 8.2 kW (11 hp)

Capital Investment:

Facilities	
Lagoons	$ 3,200
Contingency and contractor's fee	415
Total facility cost	$ 3,615
Land	350
Equipment	
Lime precipitation unit	6,950
Piping	16,000
Equipment subtotal	22,950
Contingency and contractor's fee	2,985

Total equipment cost	25,935
Total Capital Investment	$ 29,900

Annual Cost:

Amortization

Facility	$ 370
Equipment	3,865
Total amortization	$ 4,235

Operation and Maintenance (O&M)

Land	35
Operating personnel	9,450
Facility repair and maintenance	95
Equipment repair and maintenance	1,150
Materials	1,840
Taxes	10
Insurance	300
Total O&M costs	$ 12,880

Electricity	1,100
Total Annual Cost	$ 18,215

Level B: Level A plus Sulfide Precipitation

In addition to level-A treatment, sulfide precipitation is recommended. Sodium sulfide is added at a rate of 1 mg/l to the wastewater stream with the lime. Total costs for level-B treatment are shown in Table VIII-27.

The incremental capital and operating costs (sulfide precipitation only) and assumptions for attaining level B are shown below.

Capital-Cost Components and Assumptions for Level B:

Sodium sulfide addition

Operating-Cost Assumptions for Level B:

Operating personnel - 1 hr/day

Sodium sulfide - 132 kg (292 lb)/year

Capital Investment:

Equipment

Sulfide precipitation unit	$ 100
Contingency and contractor's fee	13
Total Capital Investment	$ 113

Annual Cost:

Amortization	$ 15

Operation and Maintenance (O&M)

Operating personnel	$ 3,150
Equipment repair and maintenance	5
Materials	30
Total O&M costs	$ 3,185
Total Annual Cost	$ 3,200

Titanium Mines

There is one mine in this subcategory. It produces 1,180,000 metric tons (1,300,000 short tons) of ore annually. The daily mine discharge is 2,650 cubic meters (700,000 gallons) of wastewater. One level of technology is considered for this subcategory. The cost of implementing this level is shown in Table VIII-28.

Waste Water Treatment Control

Level A: Lime Neutralization and Settling

The addition of 0.9 kg of hydrated lime per 3.785 cubic meters (2 lb/1000 gallons) of wastewater is recommended for neutralization. The treated effluent is retained for one day in a settling pond before discharge.

The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

TABLE VIII-28. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE

SUBCATEGORY: Titanium Mines

PLANT SIZE: 1,180,000 METRIC TONS (1,300,000 SHORT TONS) PER YEAR OF ore mined

PLANT AGE: 30 YEARS PLANT LOCATION: New York

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	94.3				
ANNUAL CAPITAL RECOVERY	13.6				
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	23.0				
ANNUAL ENERGY AND POWER COSTS	3.0				
TOTAL ANNUAL COSTS	39.6				
COSTS($)/METRIC TON OF PRODUCT*	0.034				

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	25	20				
Fe	1.5	1.0				

*ORE MINED. TO OBTAIN COSTS/SHORT TON OF PRODUCT, MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: LIME NEUTRALIZATION AND SETTLING

Lime precipitation unit

Piping - Flow at 2 m (6.6 feet)/sec through pipe measuring 13 cm (5.1 in.) x 1000 meters (3,280 feet)

Pond - dike height of 3 meters (10 ft)
top width of 3 meters (10 ft)
capacity of 4,000 cubic meters (1,057,000 gallons)

Land - 0.3 hectare (0.75 acre)

Operating-Cost Assumptions for Level A:

Lime - 222 metric tons (245 short tons)/year

Operating personnel - 3 hr/day

Power - 22.4 kW (30 hp)

Capital Investment:

Facilities	
Lagoon	$ 7,000
Contingency and contractor's fee	910
Total facility cost	$ 7,910
Land	525
Equipment	
Lime neutralization unit	43,000
Piping	33,000
Equipment subtotal	76,000
Contingency and contractor's fee	9,880
Total equipment cost	85,880
Total Capital Investment	$ 94,315

Annual Cost:

Amortization	
Facility	$ 805
Equipment	12,800
Total amortization	$ 13,605

Operation and Maintenance (O&M)

Land	50
Operating personnel	9,450
Facility repair and maintenance	210
Equipment repair and maintenance	3,800
Materials	8,575
Taxes	15
Insurance	945
Total O&M costs	23,045
Electricity	3,000
Total Annual Cost	$ 39,650

Titanium Mills Employing Electrostatic and/or Magnetic Separation with Gravity and/or Flotation Process

There is only one mill in this subcategory. It mills 1,179,100 metric tons (1,300,000 short tons) annually and has a daily water discharge of 35,770 cubic meters (9,450,000 gallons). This mill recycles its process water; however, there is a seasonal discharge from the tailing-pond system. The discharge is approximately 757 cubic meters (200,000 gallons) a day for two months of the year.

Two levels of technology are considered. The total costs of implementing these levels are shown in Table VIII-29.

Waste Water Treatment Control

Level A: Diversion Ditching

Diversion ditching around one length and one width of the tailing pond should help to reduce stress in the system due to seasonal runoff. The exact length and width of the tailing pond are not known. Therefore, a hypothetical length and a hypothetical width are assumed.

The capital and operating costs for attaining this level are shown below and in Table VIII-29.

Capital-Cost Components and Assumptions for Level A:

Diversion ditching - 1000 meters (3,280 feet)

Capital Investment:

TABLE VIII-29. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MILL

SUBCATEGORY: Titanium Mills Employing Electrostatic and/or Magnetic Separation with Gravity and/or Flotation Process

PLANT SIZE: 1,180,000 METRIC TONS (1,300,000 SHORT TONS) PER YEAR OF ore milled

PLANT AGE: 30 YEARS PLANT LOCATION: New York

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	1.9	12.1			
ANNUAL CAPITAL RECOVERY	0.20	1.2			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	0.07	0.4			
ANNUAL ENERGY AND POWER COSTS	--	--			
TOTAL ANNUAL COSTS	0.27	1.6			
COSTS/METRIC TON OF PRODUCT*	0.0002	0.0013			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	26,800	20	0			
Ni	0.62	0.1	0			
Zn	1.2	0.2	0			
Fe	143	0.1	0			

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: DIVERSION DITCHING
LEVEL B: LEVEL A PLUS HOLDING POND (ZERO DISCHARGE)

Facilities

Diversion ditching	$ 1,650
Contingency and contractor's fee	215
Total Capital Investment	$ 1,865

Annual Cost:

Amortization	$ 190

Operation and Maintenance (O&M)

Facility repair and maintenance	$ 50
Insurance	20
Total O&M costs	70
Total Annual Cost	$ 260

Level B: Level A plus Holding Pond (Zero Discharge)

In addition to diversion ditching, a holding pond for the excess water may be necessary. This pond is located such that any runoff collected by the diversion ditching would flow into it and be stored for at least five days.

Water from the holding pond could be discharged after the suspended solids have settled. The incremental costs for the holding pond are shown below. The total costs for level-B treatment are shown in Table VIII-29.

Capital-Cost Components and Assumptions for Level B:

Pond - dike height of 3 meters (10 ft)
top width of 3 meters (10 ft)
capacity of 5,678 cubic meters (1,500,000 gallons)

Capital Investment:

Facilities

Lagoon	$ 9,000
Contingency and contractor's fee	1,170
Total Capital Investment	$10,170

Annual Cost:

Amortization	$ 1,035

Operation and Maintenance (O&M)

Facility repair and maintenance	$ 270
Insurance	100
Total O&M costs	370
Total Annual Cost	$ 1,405

Platinum Mine/Mills Employing Dredging

There is one known platinum mine/mill complex. The daily discharge of wastewater is 32,702 cubic meters (8,640,000 gallons). Annual ore production is 2,267,500 metric tons (2,500,000 short tons).

Two alternative levels of treatment are considered. The total costs of implementing these levels are shown in Table VIII-30.

Waste Water Treatment Control

Level A: Coagulation with Alum

It is assumed that the addition of 25 mg/l of alum is sufficient for coagulation. The necessary settling ponds have already been constructed.

The alum feed system consists of two mixing tanks, each having a capacity of 16.5 cubic meters (4,359 gallons), and two positive-displacement pumps for adding the alum solution. The alum solution is mixed and fed to the wastewater stream at a 1-percent solution. The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level A:

two mix tanks, each with capacity of 16.5 cubic meters (4,359 gallons)
two positive-displacement pumps

Operating-Cost Assumptions for Level A:

Alum - 285 metric tons (315 short tons)/year

Operating personnel - 5 mixes/day @ 1 hr/mix

TABLE VIII-30. WATER EFFLUENT TREATMENT COSTS AND RESULTING WASTE-LOAD CHARACTERISTICS FOR TYPICAL MINE/MILL

SUBCATEGORY: Platinum Mine/Mills Employing Dredging

PLANT SIZE: 2,267,500 METRIC TONS (2,500,000 SHORT TONS) PER YEAR OF material handled

PLANT AGE: ~40 YEARS PLANT LOCATION: Alaska

a. COSTS OF TREATMENT TO ATTAIN SPECIFIED LEVELS

COST CATEGORY	COSTS ($1000) TO ATTAIN LEVEL				
	A	B	C	D	E
TOTAL INVESTED CAPITAL	18.0	16.8			
ANNUAL CAPITAL RECOVERY	2.7	2.5			
ANNUAL OPERATING AND MAINTENANCE COSTS (EXCLUDING ENERGY AND POWER)	35.6	73.5			
ANNUAL ENERGY AND POWER COSTS	1.1	1.3			
TOTAL ANNUAL COSTS	39.4	77.3			
COSTS ($)/METRIC TON OF PRODUCT*	0.017	0.034			

b. RESULTING WASTE-LOAD CHARACTERISTICS

PARAMETER	CONCENTRATION (mg/ℓ) (ppm)					
	RAW (UN-TREATED)	AFTER TREATMENT TO LEVEL				
		A	B	C	D	E
TSS	80,000	30	30			

*ORE MILLED. TO OBTAIN COSTS/SHORT TON OF PRODUCT (ORE MILLED), MULTIPLY COSTS SHOWN BY 0.907

LEVEL A: COAGULATION WITH ALUM
LEVEL B: FLOCCULATION

Power - 8.2 kW (11 hp)

Capital Investment:

Equipment

Alum feed system	$ 15,900
Contingency and contractor's fee	2,070
Total Capital Investment	$ 17,970

Annual Cost:

Amortization	$ 2,680
Operation and Maintenance (O&M)	
Operating personnel	$ 15,750
Equipment repair and maintenance	795
Materials	18,900
Insurance	180
Total O&M costs	$ 35,625
Electricity	1,100
Total Annual Cost	$ 39,405

Level B: Flocculation

The flocculant feed system is the same as that previously described. However, for this operation, the recommended dosage of flocculant is 2 mg/l.

Level-B costs are shown in Table VIII-30. This level is not an addition to level-A treatment, but an alternative for it. The capital and operating costs and assumptions for attaining this level are shown below.

Capital-Cost Components and Assumptions for Level B:

Flocculant feed system

Operating-Cost Assumptions for Level B:

Flocculant - 23 metric tons (25.2 short tons)/year

Total Capital Investment	$ 12,430

Power - 9.7 kW (13 hp)

Capital Investment:

Flocculant feed system	$ 14,900
Contingency and contractor's fee	1,940
Total Capital Investment	$ 16,840

Annual Cost:

Amortization	$ 2,510
Operation and Maintenance (O&M)	
Operating personnel	$ 22,050
Equipment repair and maintenance	845
Materials	50,400
Insurance	170
Total O&M costs	$ 73,465
Electricity	1,300
Total Annual Cost	$ 77,275

NON-WATER QUALITY ASPECTS

The treatment and control technologies proposed for use by the ore mining and dressing industry present a number of non-water quality aspects which are discussed below.

Air and Noise Pollution

The type of equipment and processes used in water treatment and water recycling present no air or noise pollution problems. In general, water treatment plants are isolated and noise which is generated by equipment reaches only those personnel in close proximity to the plant. It should be noted, however, that large, unstabilized tailing disposal areas used for process wastes are often a source of air pollution in the form of dust.

Availability of Chemicals

Although many mining operations are remotely located, water treatment chemicals such as lime and flocculating agents are readily available in the quantities needed. These chemicals may require transportation over long distances, but no cases were reported where treatment reagents were difficult to obtain.

By-Product Recovery

By-product recovery resulting from the proposed treatment and control technologies occurs in the uranium and ferroalloy segments of the industry. Uranium and vanadium are being recovered from uranium ore leaching solutions by using an ion exchange resin, yielding cost benefits through water treatment.

Molybdenum is recovered from wastewater on a pilot scale basis by ion exchange in the ferroalloy segment, but by-product recovery in other segments of the industry is either uneconomical or technologically unfeasible at the present time.

Ground Water Contamination

Seepage and infiltration of wastewater from impoundments into the ground may occur if tailing ponds, settling basins and lagoons are not properly designed. Since wastewater is often impounded over large tracts of land, the opportunities for infiltration of chemical and radiological pollutants into ground water are greatly increased. Nevertheless, various techniques for seepage prevention are available, and ground water contamination can be avoided in well-designed impoundments.

Land Requirements

Since most mining and milling operations employ sizable earthen impoundments for holding water, land requirements can become very significant. Both the iron and copper segments of the industry typically employ large tailing ponds, up to 1575 ha (6 sq mi) and 2100 ha (8 sq mi), respectively. Although these ponds are generally located in areas where land is available, other mining and milling operations are restricted to areas where local topography and geography severely limit the amount of suitable impoundment sites.

Energy Requirements

The energy amounts and costs required through application of the proposed treatment and control technologies have been estimated in Section VIII as a portion of the total cost necessary to employ the recommended technologies.

Solid-Waste Disposal

Solid-waste disposal associated with wastewater treatment in the ore mining and dressing industry is an increasing problem. Wastewater treatment includes removal of certain dissolved or suspended components from wastewater, and the removed material must be recognized as a solid-waste problem.

Most water-treatment-related impoundments, such as settling basins and lagoons, collect considerable quantities of settleable solids, and dredging is usually necessary to facilitate continued operation of the lagoon. The dredged solids are frequently landfilled or returned to the mines for disposal.

Effective disposal of water-treatment-derived solids demands that measures be taken to prevent leaching of soluble components from the solids. Analysis of tailing-pond solids reveals high concentrations of heavy-metal pollutants in all industry segments. Acidification of tailing-pond waters through addition of acid water from smelters, refineries, mines and pollution-control devices may solubilize these heavy metals. Land disposal of sludges should be planned so that drainage does not leach pollutants from the disposed material.

The quantities of solid wastes associated with mining (both low-grade, unusable ores and overburden resulting from open-pit operations) and milling (i.e., concentrator tailings, or gangue) are very large. Unfortunately, virtually no statistics are available to indicate the magnitude of the problem for the ore mining and dressing industry as a whole. However, incomplete data recently published (October 1976) in Reference 75 indicate trends and have been used to prepare Table VIII-31. These 1974 data reflect the "waste rock," "overburden," and "concentrator tailings" types of solid wastes, which reflect the larger portion of all solid wastes; however, they do not consider the solid wastes (sludges, slimes, etc.) resulting from wastewater-treatment processes which may be generated by reagent addition. Additionally, they consider the solid wastes from only five of the ten ore categories treated by the present document, ignoring those of the gold; silver; aluminum (bauxite); ferroalloy-metal; and, probably most significant of all, iron ore categories. Nevertheless, Table VIII-31 shows that over 770 million metric tons (over 847 million short tons) of solid wastes, excluding wastewater-treatment wastes, were produced in 1974 from just five of the ten metal-ore categories. Of this waste, 48.3% was waste rock, 18% was overburden, and 33.7% was concentrator tailings. Reference 75 predicts that, compared to 1974, these wastes will increase 16% in 1977 and 58% in 1983.

Radioactive Materials

The uranium-ore mining and milling industry may produce wastes which are not compatible with environmental health and which may require additional handling safeguards, such as stabilization of tailing-disposal areas, treatment lagoon lining, etc. About 70% of the original activity in the ore remains with the tailings. This provides an indefinite source of radioactivity.. Radon-222, a radioactive gas, is produced by the decay of radium-226. This gas diffuses through the tailings and is released to the atmosphere. The amount of radon diffusing into the atmosphere depends upon a number of factors, including the radium-226 content of the tailings, the water content of the tailings, the tailing depth, and the tailings pile dimensions. Because of the high radium-226 content of the tailings, the piles can be a significant source of radon-222 for an indefinite period. Control steps such as pile stabilization to reduce wind blowing and tailings and erosion as well as covering the tailings with asphalt, earth or other materials can minimize their impact as a potential source of radiation exposure.

TABLE VIII-31. PRINCIPAL DRY SOLID WASTES GENERATED BY SELECTED ORE CATEGORIES IN 1974

TYPE OF WASTE	ANNUAL AMOUNT GENERATED, BY ORE CATEGORY, IN METRIC TONS (SHORT TONS)					
	COPPER	LEAD/ZINC	MERCURY[*]	URANIUM/RADIUM/ VANADIUM	ORES, NOT ELSEWHERE CLASSIFIED[†]	TOTALS
WASTE ROCK (BARREN OR LOW-GRADE ORES)	365,657,000 (403,067,000)	1,866,000 (2,057,000)	908,000 (1,001,000)	2,268,000 (2,500,000)	1,051,000 (1,159,000)	371,750,000 (407,784,000)
OVERBURDEN	44,511,000 (49,065,000)	0	487,000 (537,000)	94,497,000 (104,165,000)	0	139,495,000 (153,767,000)
CONCENTRATOR TAILINGS (GANGUE) (LESS WATER)	240,794,000 (265,430,000)	12,430,000 (13,702,000)	16,000 (18,000)	6,083,000 (6,705,000)	318,000 (351,000)	259,641,000 (286,206,000)
TOTAL WASTE[**]	650,962,000 (717,562,000)	14,296,000 (15,759,000)	1,411,000 (1,556,000)	102,848,000 (113,370,000)	1,369,000 (1,386,000)	770,886,000 (847,757,000)

[*] Excludes production (unavailable) for operations closed in 1974.

[†] Excludes production (unavailable) for platinum operation.

[**] Excludes sludges, slimes, dusts, and all other wastes resulting from wastewater-treatment or air-emission treatment processes.

Based on Reference 75.

SECTION IX

BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE, GUIDELINES AND LIMITATIONS

INTRODUCTION

The effluent limitations which must be achieved by July 1, 1977 are based on the degree of effluent reduction attainable through the application of the best practicable control technology currently available. For the ore mining and dressing industry, this level of technology is based on the average of the best existing performance by facilities of various sizes, ages, and processes within each of the industry's subcategories. In Section IV, the ore mining and dressing industry was initially divided into ten major categories. Several of these major categories have been further subcategorized, and, for reasons explained in Section IV, each subcategory will be treated separately for the recommendation of effluent limitation guidelines and standards of performance. As also explained in Section IV, the subcategories presented in this section will be consolidated, where possible, in the regulations derived from this development document.

Best practicable control technology currently available emphasizes treatment facilities at the end of a manufacturing process but also includes the control technology within the process itself when it is considered to be normal practice within an industry. Examples of waste management techniques which are considered normal practice within these industries are:

(a) manufacturing process controls;
(b) recycle and alternative uses of water; and
(c) recovery and reuse of some wastewater constituents.

Consideration was also given to:

(a) the total cost of application of technology in relation to the effluent reduction benefits to be achieved from such application;
(b) the size and age of equipment and facilities involved;
(c) the process employed;
(d) the engineering aspects of the application of various types of control techniques;
(e) process changes; and
(f) nonwater-quality environmental impact (including energy requirements).

It was determined that the quantity of mine water discharged (and consequently mass waste loadings) was dependent upon many factors beyond the control of the mine operator and unrelated or only indirectly related to mine production; therefore, effluent limitations based on concentrations only (with the exception of pH units) are recommended for all mining subcategories.

The quantity of mill process water used (and mill process waste water discharged) within a subcategory is based primarily upon the mineralogy of the ore being processed which affects the fineness of grind required to liberate the metal values and the processes required to concentrate the metal values. Because of the variables within a subcategory affecting the quantity of mill process wastewater discharged, a relationship between production and discharge (flow or mass waste loadings) could not be developed; effluent limitations based on concentrations only (with the exception of pH units) are recommended for all milling subcategories.

It was also determined that for a number of milling subcategories, BPCTCA, BATEA and NSPS were no discharge of wastewater pollutants to navigable waters. This limitation was not intended to prohibit a facility to discharge wastewater to an available treatment system which might be present in a combined mine and mill complex.

To preclude a facility from treating only a portion of the mine water in a combined system so that the requirement for recycle of mill process water can be circumvented, or by using a good quality mine water for dilution to avoid both recycle and treatment of mill process water, the following criteria should be applied to a combined treatment system:

(a) If both the mine and the mill are allowed a discharge of pollutants, the quantity or quality of each pollutant or pollutant property in the combined discharge that is subject to effluent limitations should not exceed the quantity or quality of each pollutant or pollutant property that would have been discharged had each waste stream been treated separately.

(b) If the mill is allowed no discharge of pollutants, the following conditions should be met:

 (1) a reduction in pollutants attributable to mine water should be shown,

(2) all of the mine water should be treated in the combined system,

(3) the discharge flow should not exceed the flow from the mine minus any make-up water used in the mill, and,

(4) the quantity or quality of each pollutant or pollutant property in the combined discharge that is subject to effluent limitations should not exceed the quantity or quality of each pollutant or pollutant property that would have been discharged had each stream been treated separately.

No discharge of wastewater pollutants from a number of ore dressing facilities can be realized in those areas where rainfall does not exceed evaporation. In areas where the annual rainfall exceeds evaporation (as defined by the National Weather Service for the location of the facility). It is recommended that a volume of water equivalent to the difference between annual rainfall and annual evaporation on the tailings pond be allowed to be discharged subject to the recommended effluent limitations for the combined mine and mill discharges.

In the event that waste streams from various sources in addition to mines and mills (such as smelters, acid plants, etc.) are combined for treatment and discharge, the quantity or quality of each pollutant or pollutant property in the combined discharge that is subject to limitations (set forth in this document or in other documents) should not exceed the quantity or quality of each pollutant or pollutant property that would have been discharged had each waste stream been treated separately.

The following is a discussion of the best practicable control technology currently available for each of the subcategories, and the proposed limitations on the pollutants in their effluents.

GENERAL WATER GUIDELINES

Process Water

Process water is defined as any water used in the mill or in the ancillary operations required for beneficiating the ore and contacting the ore, processing chemicals, intermediate products, byproducts, or products of a process, including contact cooling water. All process water effluents are limited to the pH range of 6.0 to 9.0 unless otherwise specified.

Mine Drainage/Mine Water

Mine drainage/mine water is defined as any water drained, pumped or siphoned from an ore mine.

Cooling Water

In the ore mining and dressing industry, cooling and process waters are sometimes mixed prior to treatment and discharge. In other situations, cooling water is discharged separately. Based on the application of best practicable control technology currently available, the recommendations for the discharge of such cooling water are as follows:

An allowed discharge of all non-contact cooling water provided that the following conditions are met:

(a) Thermal pollution be in accordance with standards to be set by EPA policies. Excessive thermal rise in once-through non-contact cooling water in the ore mining and dressing industry has not been a significant problem.

(b) All non-contact cooling waters be monitored to detect leaks of pollutants from the process. Provisions should be made for treatment to the standards established for process wastewater discharges prior to release in the event of such leaks.

(c) No untreated process waters be added to the cooling waters prior to discharge.

The above non-contact cooling water recommendations should be considered as interim, since this type of water plus blowdowns from water treatment, boilers, and cooling towers will be regulated by EPA at a later date as a separate category.

Storm-Water Runoff

Storm water runoff may present pollution control problems whenever the runoff passes over an area disturbed by the ore mining operation or the ore dressing operation, where there are stock piles of ore to be processed or where waste materials are stored.

Facilities should be designed to treat or contain this runoff, however, regardless of the size of the treatment facility, there are natural occurrences which might result in the system being overloaded with the resultant discharge violating the effluent limitations set forth in this section. To provide guidance to be used in the design of a treatment system and to avoid the legal problems that might result if an unauthorized discharge occurs, the following provisions are recommended:

> Any untreated overflow which is discharged from facilities designed, constructed and operated to contain all process generated wastewater and the surface runoff to the treatment facility, resulting from a ten-year, 24-hour precipitation event and which occurs during or directly as a result of a precipitation event shall not be subject to the limitations set forth in this section.

The term "ten-year, 24-hour precipitation event" means the maximum 24-hour precipitation event with a probable reoccurrence of once in 10 years as defined by the National Weather Service and Technical Paper No. 40, "Rainfall Frequency Atlas of the U.S.,: May 1961 and subsequent amendments or equivalent regional or rainfall probability information developed therefrom. It is intended that when subsequent events occur, each of which results in less precipitation than would occur during a "ten-year, 24-hour precipitation event", that result in an equivalent amount of runoff, the same provisions will apply.

BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE BY ORE CATEGORY AND SUBCATEGORY

Category: Iron Ores

Subcategory: Iron-Ore Mines

This subcategory includes mines operated to obtain iron ore, regardless of the type of ore or its mode of occurrence. The limitations proposed here apply to the discharge and treatment of mine waters.

Identification of BPCTCA. Best practicable control technology currently available (BPCTCA) for the control of wastewater from the mining of iron ore is settling ponds with coagulation/ flocculation systems. At selected locations, it may be possible to employ settling ponds alone to meet the effluent limitations specified herein. For acid mine discharge, lime-neutralization technology is wellunderstood and is generally applied in other mining industries. Adjustment of wastewater pH prior to discharge may be necessary.

To implement this technology for use at facilities not already employing the recommended treatment techniques, settling impoundments with dispersal systems available for delivery of flocculating agents will need to be constructed.

Rationale for Selection. At least five iron-ore mines are known to be currently employing settling impoundments for treatment of mine wastewater. Suspended-solid removal is enhanced by coagulation/flocculation systems, as demonstrated at one mill tailing-impoundment system.

Levels of Effluent Reduction Attainable. The levels of effluent parameters in wastewaters attainable, using the above technology, are summarized in Table IX-1.

Subcategory: Iron Ore Mills Employing Physical and Chemical Separation and Mills Using Only Physical Separation (Magnetic and Non-Magnetic)

This subcategory contains iron-ore milling operations that employ chemical and physical methods, and operations which employ only physical methods to beneficiate iron ore. Mine waters used in milling processes, or mine waters discharged to mill treatment facilities, are subject to the limitations proposed below.

Identification of BPCTCA. Best practicable control technology currently available for the control of wastewater from the milling of iron ore in this subcategory is the use of tailing ponds with coagulation/flocculation systems. Adjustment of wastewater pH prior to discharge may be necessary.

Rationale for Selection. Every known iron-ore beneficiation facility in this subcategory currently employs tailing-pond impoundment treatment facilities. The use and efficiency of flocculating agents have been demonstrated at one milling tailing-impoundment system.

Effluent reduction attainable through the use of the above technology are summarized in Table IX-2.

TABLE IX-1. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–IRON-ORE MINES

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Dissolved Fe	1.0	2.0

* Value in pH units

TABLE IX-2. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–IRON-ORE MILLS EMPLOYING PHYSICAL METHODS AND CHEMICAL SEPARATION AND ONLY PHYSICAL SEPARATION

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Dissolved Fe	1.0	2.0

*Value in pH units

Subcategory: Iron Ore Mills Employing Magnetic and Physical Separation (Mesabi Range).

This subcategory includes milling operations employing magnetic and physical separation.

Identification of BPCTCA. The best practicable control technology currently available for the control of wastewater from this subcategory is no discharge of wastewater.

Rationale for Selection. To implement this technology, no additional technology is needed, because most mills operating in this subcategory are currently attaining zero discharge by the use of large tailing ponds for effective settling of suspended solids prior to reuse and recycle of water back to the mill for processing. The use of clarifiers and thickeners to reduce the volume of water discharged to the tailing pond, and to supply water for recycle back to the milling operation, can reduce costs incurred in pumping, as well as pipe size and energy requirements, for implementation of this technology.

Levels of Effluent Reduction Attainable. Zero discharge of pollutants can be attained by use of the above technology.

Category: Copper Ores

Subcategory: Copper-Ore Mines

This subcategory includes operations obtaining copper ore from open-pit, underground, and overburden or ore stripping operations.

Identification of BPCTCA. The best practicable control technology currently available for the discharge of wastewater from the mining of copper ores is the use of lime precipitation and settling or clarification with pH adjustment prior to discharge, if necessary. This may include (1) combination of mine water with limed mill tails prior to settling (2) addition of lime to mine water directly or to mine water and mill water tailing pond effluent, with subsequent settling or clarification.

Implementation of this technology can be enhanced by reduction or elimination of discharge through the application of one or more of several techniques: (1) Reuse of water in other operations, such as leaching or milling; (2) Control of mine-water drainage by modification of mining techniques, and (3) Use of solar radiation to evaporate excess water.

Rationale for Selection. Six primary copper mines discharge mine water to surface waters. Three of these operations treat the water by lime precipitation and settling before its discharge.

Levels of Effluent Reduction Attainable. The levels of effluent parameters in wastewaters attainable using the above technology are presented in Table IX-3.

Subcategory: Copper Mines Employing Hydrometallurgical Processes

This subcategory includes mining operations employing dump, heap, or in-situ leach processes for the extraction of copper from ores or ore waste materials.

Identification of BPCTCA. The best practicable control technology currently available in this subcategory is no discharge of hydrometallurgical process wastewater.

To achieve this limitation, reuse, recycle, and consumption of water by evaporation may be employed, resulting in no discharge of water:

Leach Solution Within the Dump/Ore Bed: Dams, ditches, and collection ponds are needed to enable the acid-leach solution to be recovered and fully contained.

Barren Leach Solution: Barren, or used, acid solutions should be retained in holding ponds and recycled to the waste ore body for reuse.

Leach Solution Bleed: The use of concrete holding ponds for precipitation and settling of dissolved solids prior to evaporation or recycling of water is necessary to achieve no discharge of these solutions.

Rationale for Selection. All operations surveyed currently practice recycle and achieve zero discharge of process water.

Levels of Effluent Reduction Attainable. Zero discharge is attainable for solutions resulting from the operations of this subcategory.

TABLE IX-3. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–COPPER MINES

PARAMETERS	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Cu	0.15	0.30
Pb	0.3	0.6
Hg	0.001	0.002
Zn	0.75	1.5

*Value in pH units

Subcategory: Copper Mills Employing Vat-Leaching Process

This subcategory includes those operations employing the vat-leach method of copper extraction from ores.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is no discharge of process wastewater.

To achieve this limitation, reuse, recycle, and consumption of process water by evaporation may be implemented. The total containment of vat-leach solutions in tanks or vats, with total recycle to the process, is necessary to implement the above control technology.

Rationale for Selection. Zero discharge of vat-leach barren solution is currently practiced at all facilities. Of the four operations examined, three recycle all solutions, and one reuses the acidic process water in the production of acid from smelter gases containing sulfur dioxide.

Levels of Effluent Reduction Attainable. Zero discharge of process wastewater is attainable through the use of the above control technology.

Subcategory: Copper Mills Employing Froth Flotation

This subcategory includes those copper milling operations which employ the froth-flotation process.

Identification of BPCTCA. The best practicable control and treatment technology currently practiced within this subcategory is lime precipitation and settling, coupled with at least partial recycle of process wastewater. Adjustment of wastewater pH prior to discharge may be necessary.

Rationale for Selection. Within this subcategory, there are a number of major copper mills currently practicing recycle of zero to 90 percent of the process-water volume. Two of these operations treat their process wastewater with additional lime prior to settling in a tailing impoundment.

Levels of Effluent Reduction Attainable. The levels of concentration and waste loading attainable by implementation of the technology recommended above are presented in Table IX-4.

TABLE IX-4. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA—COPPER MILLS USING FROTH FLOTATION

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
CN	0.1	0.2
Cd	0.05	0.1
Cu	0.15	0.30
Hg	0.001	0.002
Pb	0.3	0.6
Zn	0.5	1.0

*Value in pH units

Category: Lead and Zinc Ores

Subcategory: Lead and Zinc Mines

This subcategory includes mines operated for the recovery of lead and zinc ores.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is the use of lime precipitation in combination with a settling or sedimentation pond. An alternative technology which may be employed is the use of high-density sludge neutralization process with a clarifier. Retention time must be adequate to meet or exceed the TSS limitation. Adjustment of wastewater pH prior to discharge may be necessary.

Rationale for Selection. The levels proposed for this subcategory are based on application of this technology at one zinc/copper mining operation, as well as on extensive application of this treatment at lead/zinc/copper mines in Canada, both at full-scale operations and in pilot-evaluation facilities (References 69, 71, and 76).

Levels of Effluent Reduction Attainable. The levels of effluent reduction attainable in this subcategory through the application of the above technology are presented in Table IX-5.

Subcategory: Lead and Zinc Mills

This subcategory includes all mills operated for the recovery of lead or zinc concentrates. All current operations in this subcategory employ the process of froth flotation for the beneficiation of ores.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is a settling- or sedimentation-pond system with a primary tailing pond and a secondary settling or "polishing" pond. pH adjustment of the wastewater may be necessary prior to discharge. The use of cyanide removal technology (ozonation, alkaline chlorination, peroxide addition) may be necessary during six to eight months of the year at one facility in this subcategory.

Rationale for Selection. Currently, approximately 20 percent (at least six of the operations surveyed) have implemented the above technology.

TABLE IX-5. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–LEAD AND ZINC MINES

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Cu	0.15	0.30
Hg	0.001	0.002
Pb	0.3	0.6
Zn	0.75	1.5

*Value in pH units

Levels of Effluent Reduction Attainable. The levels of effluent reduction attainable by application of the above technology are presented in Table IX-6.

Category: Gold Ores

Subcategory: Gold Mines

This subcategory includes mines operated for the recovery of gold ores by open-pit or underground methods. Discharge of mine wastewater into mill waste-treatment systems, or reuse of mine water in the milling process, is acceptable provided that effluent limitations for the mill subcategory are met, and provided that unfavorable water balances affecting mill waste-treatment systems do not result.

Identification of BPCTCA. The best practicable control technology currently available for the discharge of wastewater resulting from the mining of gold ores is the use of lime precipitation methods in conjunction with settling-pond removal of suspended solids and precipitates. Adjustment of wastewater pH prior to discharge may be necessary. Settling of suspended solids may be performed either in settling impoundments or by the use of mechanical clarification equipment to meet the levels of effluent reduction specified here.

Rationale for Selection. Treatment of mine wastewater as currently practiced by these operations varies from non-existent to the use of settling impoundments. Because the level of treatment which results is uniformly inadequate, the well demonstrated technology of chemical precipitation is specified because of its demonstrated use and efficiency of treatment attained in other categories of the ore mining and dressing industry.

Levels of Effluent Reduction Attainable. The levels of effluent reduction attainable through the use of the above technology are presented in Table IX-7.

Subcategory: Gold Mills or Mine/Mills Employing Cyanidation

This subcategory includes operations obtaining gold by the cyanidation process of extraction from gold ores.

Identification of BPCTCA. The best practicable control technology currently available in this subcategory is no discharge of process wastewater.

TABLE IX-6. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA—LEAD AND/OR ZINC MILLS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Cyanide	0.1	0.2
Cd	0.05	0.1
Cu	0.15	0.30
Hg	0.001	0.002
Pb	0.3	0.6
Zn	0.5	1.0

*Value in pH units

TABLE IX-7. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–GOLD MINES

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Cu	0.15	0.30
Hg	0.001	0.002
Pb	0.3	0.6
Zn	0.75	1.5

*Value in pH units

Implementation of this control technology may be achieved in either of two ways: impoundment or complete recycle of process wastewater. At some locations, destruction of cyanide by alkaline chlorination (or other oxidation methods such as ozonation or peroxide addition) may be necessary if the presence of cyanide in recycled water adversely affects the process.

Rationale for Selection. Of the two mills currently employing cyanidation processing, one operation has achieved zero discharge by impoundment and recycle of process wastewater. An important engineering aspect of a zero-discharge system is the design of the water-management system. A recycle system generally involves discharge of mill process water to a tailing pond for settling of solids and subsequent decantation and pumping of clarified pond water back to the mill.

A measure of control over the quality of the reclaim water is normally maintained by the use of a two-celled pond system. Tailings are discharged to the first pond for settling; then, the decant from this pond is collected in the second pond, which serves as a surge pond in the recycle system.

Level of Effluent Reduction Attainable. Zero discharge of pollutants is attainable by implementation of the above control technology.

Subcategory: Gold Mills Employing Amalgamation

This subcategory includes mills extracting gold by use of the amalgamation process.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is lime precipitation in conjunction with sedimentation or tailing impoundment, with in-process recycle of the mercury reagent in the amalgamation process. Adjustment of the pH of waste waters prior to discharge may be necessary.

Rationale for Selection. Currently, there is one operating facility employing the amalgamation process for gold extraction. To effect removal of heavy metals, the use of chemical precipitation methods in conjunction with tailing impoundment is well-documented and has been demonstrated in the ore mining and dressing industry at other locations.

Levels of Effluent Reduction Attainable. The levels of effluent reduction attainable for this subcategory by use of the above technology are presented in Table IX-8.

Subcategory: Gold Mills Employing Froth Flotation Process

This subcategory includes mills or mine/mill complexes operated for the beneficiation of gold ores by froth flotation. The single operation employing this method also practices cyanidation of tailings from the flotation circuit by agitation/cyanidation.

Identification of BPCTCA. The best practicable control technology currently available in this subcategory is the use of lime precipitation, tailing impoundments and partial recycle of process water to reduce discharge volume. If cyanide is present in wastewater, alkaline chlorination for cyanide destruction in discharge waters may be necessary.

Rationale for Selection. The single operating facility in this subcategory currently practices impoundment during approximately nine to ten months of the year. Reduction of discharge volume on a seasonal basis is possible by recycle of tailing decant water in conjunction with alkaline chlorination to remove cyanide (which would interfere with the flotation of the gold-bearing ore).

Levels of Effluent Reduction Attainable. The levels of effluent reduction attainable for this subcategory by use of the above technology are presented in Table IX-9.

Subcategory: Gold Mills or Mine/Mills Employing Gravity Separation Methods

This subcategory includes mills or mine/mills beneficiating gold ore by gravity-separation methods. This subcategory also includes placer or dredge mining or concentrating operations, as well as hydraulic-mining operations.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is the use of settling or tailing impoundments for settling of suspended solids. An alternative technology which may be employed is the pumping of wastewater from dredging operations back to a tailing-disposal area for filtration through sands and gravels. At some operations, it may be necessary to employ flocculating agents to enhance settling of suspended solids to meet the effluent limitations specified herein.

TABLE IX-8. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–GOLD MILLS USING AMALGAMATION PROCESS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Cu	0.15	0.30
Hg	0.001	0.002
Zn	0.5	1.0

*Value in pH units

TABLE IX-9. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–GOLD MILLS USING FLOTATION PROCESS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Cyanide	0.1	0.2
Cd	0.05	0.10
Cu	0.15	0.30
Hg	0.001	0.002
Pb	0.3	0.6
Zn	0.5	1.0

*Value in pH units

Rationale for Selection. The practice specified is the best technology now utilized at several operations recovering gold by gravity-separation methods. The prevailing practice in this industry subcategory is direct discharge of wastewater.

Levels of Effluent Reduction Attainable. The levels of effluent reduction attainable employing the above technology are given in Table IX-10.

Subcategory: Mill Operations Where Gold is Recovered as Byproduct of Base-Metal Milling Operation

This subcategory includes facilities operated primarily to obtain concentrates of base metals (usually lead, zinc, or copper). Gold may be obtained from the base-metal concentrates at a refinery or a smelter.

Identification of BPCTCA. No separate technology or limitations are recommended for this subcategory. Instead, the limitations and technology for each applicable base-metal subcategory are recommended, because the characteristics of the primary ore and processes employed dominate the wastewater parameters.

Category: Silver Ores

Subcategory: Silver Mines (Alone)

This subcategory includes facilities which are operated for the mining of silver ores by open-pit or underground methods. Discharge of mine waters into mill treatment systems, or for reuse as process water, is covered in the applicable limitation guidelines for milling subcategories.

Identification of BPCTCA. The best practicable control technology currently available for silver-mine discharges is use of lime precipitation for heavy-metal removal in conjunction with the use of settling pond(s) for suspended solid removal. An alternative suspended-solid treatment is the use of mechanical clarifiers. At selected locations, pH adjustment of discharge waters may be necessary.

Rationale for Selection. Current treatment practices in the silver mining industry range from no treatment to use of settling ponds where discharge to mill treatment systems or use in a mill process is not practiced. Treatment practices are considered to be uniformly inadequate for the removal of pollutants present in silver-mine wastewater. Therefore,

TABLE IX-10. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA—GOLD MINES OR MILLS USING GRAVITY-SEPARATION METHODS

PARAMETER	CONCENTRATION (mℓ/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
Set.Solids	—	0.5

*Value in pH units

lime treatment methods which have been demonstrated to be effective in other segments of the ore mining and dressing industry have been adopted in addition to use of settling ponds.

Levels of Effluent Reduction Attainable. The levels of effluent reduction attainable through the use of the above technology are presented in Table IX-11.

Subcategory: Silver Mills Employing Froth Flotation

This subcategory includes those milling operations employing the forth-flotation process for extraction of silver concentrates from silver ores.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is the use of lime precipitation in conjunction with tailing impoundments and partial or total recycle of process water. pH adjustment of wastewater prior to discharge may be necessary.

Rationale for Selection: Current treatment practices in the silver industry is the use of settling ponds and partial or complete recycle of process water.

Levels of Effluent Reduction Attainable. The levels of effluent reduction attainable for this subcategory by use of the above technology are presented in Table IX-12.

Subcategory: Mills or Mine/Mills Using Cyanidation for Recovery of Silver

This subcategory includes those milling operations employing the cyanidation process for recovery of silver from silver ores. The recovery of silver by this method is usually done in connection with gold recovery.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is attainment of zero discharge by use of recycle or total impoundment of process water.

To implement this technology, recycling in the process reagent circuits may be necessary to achieve economy in reagent use and avoid high concentrations of cyanide in recycled process water.

TABLE IX-11. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–SILVER MINES (ALONE)

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Cu	0.15	0.30
Hg	0.001	0.002
Pb	0.3	0.6
Zn	0.75	1.5

*Value in pH units

TABLE IX-12. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–SILVER MILLS USING FROTH FLOTATION PROCESS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6 to 9*	6 to 9*
TSS	20	30
CN	0.1	0.2
Cd	0.05	0.1
Cu	0.15	0.30
Hg	0.001	0.002
Pb	0.3	0.6
Zn	0.5	1.0

*Value in pH units

Rationale for Selection. Currently, no treatment technology is being practiced at the one known discharging milling establishment in this subcategory. However, the attainment of zero discharge at a cyanidation mill in the gold category has been well-documented and demonstrated to be effective for use in similar operations involving the cyanidation process at silver mills. In addition, comparison of percentage recovery for a mill employing cyanidation for gold/silver recovery with no treatment to that of a gold mill practicing total recycle indicates that no loss of recovery is necessary with recycling of process water.

Levels of Effluent Reduction Attainable. Zero discharge of pollutants to surface waters will result with employment of the above technology.

Subcategory: Mines or Mines and Mills Extracting Silver by Use of the Amalgamation Process

This subcategory includes milling operations engaged in the recovery of silver by use of amalgamation of silver ores. This process is often employed for the extraction of both gold and silver from ores.

Identification of BPCTCA. The best practicable control technology currently available is lime precipitation for metal removal in conjunction with the use of settling impoundments. To achieve reduction of mercury concentrations in process wastewater, in-process recycling within the mercury reagent circuit should be used. The adjustment of pH of discharge waters may be necessary at selected operations to achieve pH limitations.

Rationale for Selection. At present, there is one operation utilizing amalgamation for the recovery of silver. This operation currently employs two sedimentation ponds, but metal removal by this method is inadequate. The use of chemical-precipitation methods has been well-demonstrated in the ore mining and dressing industry to be effective in reduction of heavy metal pollutant concentrations.

Levels of Effluent Reduction Attainable. The levels of pollutant concentrations attainable by use of the above methods are presented in Table IX-13.

TABLE IX-13. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–SILVER MILLS USING AMALGAMATION PROCESS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Cu	0.15	0.30
Hg	0.001	0.002
Zn	0.5	1.0

*Value in pH units

Subcategory: Silver Mills Using by Gravity-Separation Methods

This subcategory includes those operations operated for the recovery of silver by gravity-separation methods. Silver is recovered in minor amounts as part of gold placer operations.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is the use of settling or tailing impoundments for settling of suspended solids. An alternative technology which may be employed is the pumping of wastewater from dredging operations back to a tailing-disposal area for filtration through sands and gravels. At some operations, it may be necessary to enhance the settling of suspended solids to meet the effluent limitations specified here.

Rationale for Selection. The use of settling impoundments such as dredge ponds or tailing impoundments is the best technology now utilized in connection with gravity methods of extraction of silver in the dredges or placer mining industry today.

Levels of Effluent Reduction Attainable. The levels of effluent reduction attainable employing the above technology are given in Table IX-14.

Subcategory: Mill Operations Where Silver is Recovered as Byproduct of Base-Metal Milling Operation

This subcategory includes facilities operated primarily to obtain concentrates of base metals (usually, lead, zinc, or copper). Silver may be obtained from the base-metal concentrates at a refinery or a smelter.

Identification of BPCTCA. No separate technology or limitations are recommended for this subcategory. Instead, limitations and technology for each applicable base-metal subcategory are recommended, because the characteristics of the primary ore and processes employed dominate the wastewater parameters.

Category: Bauxite Ores

This category includes establishments engaged in the mining of bauxite ores. No beneficiation of these ores is currently practiced, with the exception of crushing and

TABLE IX-14. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–SILVER MILLS USING GRAVITY SEPARATION

PARAMETER	CONCENTRATION (ml/l) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
Set.Solids	–	0.5

*Value in pH units

grinding activities at the two currently operating sites. No subcategories were identified in this category.

Identification of BPCTA. The best practicable control technology currently available for the removal of pollutants present in mine drainage in the bauxite mining industry is use of lime precipitation and settling. In the case of alkaline ground-water drainage, aeration of wastewater may be necessary to convert iron to a form more amenable to lime precipitation. Adjustment of the wastewater pH prior to discharge may be necessary.

Rationale for Selection. The two currently operated facilities are both practicing lime neutralization and/or precipitation on most mine effluents at the present time. The efficiency of this method of treatment has been well-demonstrated in these operations on both full- and pilot-scale bases.

Levels of Effluent Reduction Attainable. The concentration levels attainable through implementation of BPCTA are presented in Table IX-15.

Category: Ferroalloy Ores

Subcategory: Ferroalloy Ore Mines Producing Greater Than 5,000 Metric Tons (5512 Short Tons) Per Year

This subcategory includes mines operated to obtain ferroalloy metals and which discharge to surface waters of the U.S., regardless of the particular ferroalloy metal involved. The ferroalloy-metal ores covered here include chromium, cobalt, columbium/tantalum, manganese, molybdenum, nickel, tungsten, and vanadium (recovered alone). Vanadium is also recovered as a byproduct of uranium mining and milling operations.

Identification of BPCTA. The best practicable control technology currently available for this subcategory is the use of lime precipitation in conjunction with a settling pond. For use of this technology, liming prior to removal of suspended solids is desirable. The use of a mechanical clari-flocculator or equivalent equipment is an acceptable alternative for suspended solid removal. Adjustment of wastewater pH prior to discharge may be necessary.

Rationale for Selection. Sedimentation or settling impoundments are widely used in the ore mining and dressing industry for suspended-solid removal. The use of lime for

TABLE IX-15. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–BAUXITE MINES (ACID OR ALKALINE MINE DRAINAGE)

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Al	1.0	2.0
Fe	0.5	1.0
Zn	0.1	0.2

*Value in pH units

pH adjustment and precipitation of metals is both an effective practice and a standard, longstanding practice at many milling establishments. Because metal removal by settling methods alone is inadequate at most ferroalloy-ore mines, relatively simple lime-precipitation methods are recommended for use. Engineering difficulties may be encountered where large mine flows coincide with limited land availability, but the employment of mechanical clarifying/ flocculating devices is an acceptable alternative. At one ferroalloy mining site, a mechanical device for settling suspended solids was used, and levels of less than 15 mg/l of suspended solids were attained. Adjustment of pH to the range of 8.5 to 9, with removal of solid precipitates, will enable attainment of the effluent levels recommended here.

Levels of Effluent Reduction Attainable. The levels of effluent reduction attainable and the parameters selected for control for this subcategory are presented in Table IX-16. Note that no limitation for molybdenum is recommended for BPCTCA, because this metal is not effectively removed by currently available treatment. Discharge concentrations of these metals will be minimized by sound practice (as discussed above), and by avoiding leaching of ores exposed for long periods to oxidizing conditions.

Subcategory: Mills and Mines Processing Less Than 5,000 Metric Tons (5,512 Short Tons) Per Year of Ferroalloy Ores

This subcategory includes those operations processing less than 5,000 metric tons (5,512 short tons) of ore per year by methods other than ore leaching. Operations in this subcategory are confined primarily to intermittent operation, and beneficiation of the ores is frequently performed by gravity methods. Tungsten-ore mines/mills are the prime components of this subcategory.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is the use of settling or tailing ponds in conjunction with neutralization.

Rationale for Selection. Operations in this subcategory are, in general, intermittent; economically marginal; and of a low level of technical sophistication. Present practice at these operations is predominantly direct discharge without treatment. Data gathered here indicate that current practices in this subcategory are uniformly inadequate. Therefore, the relatively simple, well-demonstrated and

TABLE IX-16. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–FERROALLOY-ORE MINES (PRODUCING > 5,000 METRIC TONS (5,512 SHORT TONS) PER YEAR

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
As	0.5	1.0
Cd	0.05	0.10
Cu	0.15	0.30
Mo	†	†
Pb	0.3	0.6
Zn	0.5	1.0

*Value in pH units

†No limitations proposed for BPCTCA

well-documented technology of tailing or settling impoundment with pH control is recommended. The use of this technology will represent a major improvement over present practice at most operations in this subcategory.

Mine water, where available, should be used for mill feed, and the mine and mill waters should be treated together. Neutralization and suspended-solid removal will result in some degree of removal of dissolved metals, in addition to reduction of COD and other waste components, by use of this technology, although monitoring of these parameters is not recommended here.

Levels of Effluent Reduction Attainable. The parameters selected and the recommended effluent levels attainable by use of the above technology in this subcategory are presented in Table IX-17.

Subcategory: Mills Processing More Than 5,000 Metric Tons (,512 Short Tons) of Ferroalloy Ores Per Year By Physical Methods

This subcategory includes mill or mine/mill facilities processing more than 5,000 metric tons (5,512 short tons) of ferroalloy ores per year by purely physical methods. These methods include ore crushing, washing, jigging, heavy-media and gravity separation, and magnetic and electrostatic separation.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is the use of process-water recycle practices in conjunction with tailing impoundment, lime precipitation, flocculation, and secondary settling. Adjustment of wastewater pH prior to discharge may be necessary.

Total recycle of process water with zero discharge is a possible viable alternative technology for many operations of this type.

Rationale for Selection. The recommended BPCTCA technology has been in large-scale use within the ore mining and dressing industry, and its successful implementation on waste streams is expected to pose no significant technical problems. Treatment to BPCTCA levels is achieved at the largest industry representative of this subcategory, although natural alkalinity and low soluble ore contents obviate the need for the practice of lime precipitation at that site. Recycle of process waters is currently practiced

TABLE IX-17. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA—FERROALLOY-ORE MINES AND MILLS PROCESSING LESS THAN 5,000 METRIC TONS (5,512 SHORT TONS) PER YEAR

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	30	50

*Value in pH units

at many sites and is limited technically only where wet scrubbers are used for air-pollution control on ore-drying or ore-roasting installations. In such operations, dissolved-solid buildup in the scrubber-water circuit could lead to decreased effectiveness in scrubbing and consequent increased maintenance. Total recycle with no process-water discharge reportedly will be practiced upon reopening of a manganiferous-ore concentrator, which is expected to occur some time during 1975.

Levels of Effluent Reduction Attainable. The parameters selected for control and the levels of effluent reduction attainable by implementation of this technology are presented in Table IX-18.

Subcategory: Mills Processing More Than 5,000 Metric Tons (,512 Short Tons) of Ferroalloy Ores Per Year By Flotation Methods

This subcategory includes mills processing more than 5,000 metric tons (5,512 short tons) of ferroalloy ores per year by froth-flotation methods.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory includes the use of primary settling or tailing ponds in conjunction with lime precipitation and secondary settling. Flocculation may be necessary at selected locations to meet suspended-solid limitations.

Lime precipitation will not be necessary at some sites, because their flotation circuits are maintained at alkaline pH. Adjustment of wastewater pH prior to discharge may be necessary.

Rationale for Selection. The recommended treatment and control technology is currently in use within the ore mining and dressing industry, and its successful implementation for waste streams from mills in this subcategory is expected to pose no significant technical problems. Because of alkaline pH at flotation mills and the use of settling ponds with adequate retention time, levels recommended here are currently being achieved at sites within the subcategory.

Recycle of process water is not recommended as BPCTCA for these operations, since nonsulfide-ore flotation operations would require extensive process development work and process modification. In addition, no successful operations are known at present which employ total recycle for fatty-acid

TABLE IX-18. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA – FERROALLOY-ORE MILLS PROCESSING MORE THAN 5,000 METRIC TONS (5,512 SHORT TONS) PER YEAR BY PHYSICAL METHODS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
As	0.5	1.0
Cd	0.05	0.1
Cu	0.15	0.30
Mo	†	†
Zn	0.5	1.0

*Value in pH units

†No limitations proposed for BPCTCA

flotation of scheelite, however, there is at least one operation that employs partial recycle for fatty-acid flotation of schelite.

Total recycle is a viable alternative technology for some mills within the subcategory--particularly, since treatment of smaller wastewater volumes may, in some cases, offer substantial economic advantages.

Levels of Effluent Reduction Attainable. The parameters selected and levels of effluent reduction attainable by implementation of BPCTCA are presented in Table IX-19. Levels of cyanide and COD can be controlled by control of reagent usage, and by natural aeration and degradation during delivery of tailings to impoundment and during retention in settling ponds.

Subcategory: Mills Processing Ferroalloy Ores By Leaching Techniques

This subcategory includes mills processing ferroalloy ores by leaching techniques (whether acid or alkaline) and associated chemical-beneficiation techniques.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory includes tailing-pond impoundment for primary settling, in conjunction with lime precipitation, flocculation, secondary settling, and segregation of wastewater streams.

The segregation of highly contaminated leaching, solvent extraction, precipitation, and scrubber waste streams from noncontact cooling water and uncontaminated waste streams is currently practiced and is essential to effective removal of metals from the wastewater. Adjustment of wastewater pH prior to discharge may be necessary.

Rationale for Selection. The recommended BPCTCA is currently in use within the ore mining and dressing industry. Control and treatment technology within the subcategory (except at one site leaching only concentrates) is inadequate at present. This results in the discharge of appreciable quantities of heavy metals, removable by lime precipitation, and in excessive suspended-solid loads as well as substantial discharges of ammonia. Since effluent streams are currently very high in sulfates (10,000 mg/l), application of lime precipitation will result in marginal decreases (estimated to be 10 to 15 percent) in total

Table IX-19. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–FERROALLOY-ORE MILLS USING FLOTATION PROCESS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
COD	50	100
Cyanide	0.1	0.2
As	0.5	1.0
Cd	0.05	0.1
Cu	0.15	0.30
Mo	†	†
Zn	0.5	1.0

*Value in pH units

†No limitations proposed for BPCTCA

dissolved solids, as well as in substantial removal of heavy metals.

Levels of Effluent Reduction Attainable. The parameters selected for control and the effluent reduction attainable by implementation of BPCTCA are presented in Table IX-20.

The limitation of Cr is not recommended using the BPCTCA. Control technology at BPCTCA is not available. Hexavalent-chromium removal requires chemical reduction, which will require development work before application to mill waste streams. Only trivalent chromium will be removed by lime precipitation.

Total dissolved solids, although a major waste constitutent, are not limited because practical control technology applicable to these operations is not currently available. Proper management of the discharge to ensure rapid mixing and dispersal can alleviate possible problems of stratification and formation of pockets of saline water in the receiving waters.

Category: Mercury Ores

Subcategory: Mercury Mines

This subcategory includes all mines, whether open-pit or underground, operated for the extraction of mercury ores.

Identification of BPCTCA. The best practicable control technology currently available is use of lime precipitation in conjunction with settling impoundments.

Chemical-precipitation methods for heavy-metal removal may include lime- or sulfide-precipitation methods. Mechanical clarifiers are an acceptable alternative method for suspended solid removal. Adjustment of the pH to acceptable levels may be necessary at some locations prior to discharge.

Rationale for Selection. The use of settling impoundments has been demonstrated to be effective in removal of suspended solids at a large number of locations. Chemical-precipitation methods are necessary to reduce heavy-metal levels because present treatment at most locations, if any is used, is inadequate. The use of lime-precipitation methods with effective pH control is a demonstrated and effective means of reducing heavy-metal concentrations. The technology selected for control of the pollutant parameters

TABLE IX-20. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA—FERROALLOY-ORE MILLS USING LEACHING PROCESS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Ammonia	1200	2400
As	0.5	1.0
Cd	0.05	0.1
Cr	†	†
Cu	0.15	0.30
Zn	0.5	1.0

*Value in pH units

†No limitations proposed for BPCTCA

named will also have the additional benefit of reducing other heavy metals as well.

Levels of Effluent Reduction Attainable. The parameters selected and the levels of effluent reduction attainable are presented in Table IX-21.

Subcategory: Mercury Mills or Mine/Mills Employing Gravity Separation Methods

This subcategory includes those mills processing mercury ores by gravity-separation methods. At present, there is one known operation employing this method.

Identification of BPCTCA. The best practicable control technology currently available is zero discharge by recycle of process water or total impoundment.

Rationale for Selection. The only operation using these methods is currently attaining zero discharge by impoundment and recycle of process water back to the process after tailing-pond treatment. A secondary pond is maintained to impound overflow should unusual conditions prevail, and to collect any seepage through the tailing impoundment. This water, if any, is pumped back to the primary tailing pond.

Levels of Effluent Reduction Attainable. Zero discharge of pollutants will result from implementation of BPCTCA.

Subcategory: Mercury Mills or Mine/Mills Using Flotation Process

This category includes those operations beneficiating mercury ores by the froth-flotation process.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is zero discharge by the use of total recycle and complete impoundment of process wastewater.

Rationale for Selection. The only known facility in this subcategory is designed to attain zero discharge by recycle and impoundment of process water. If the treatment system to be used is not found adequate to handle the total wastewater volume, provisions have already been made for construction to double the present impoundment volume and take advantage of evaporative losses.

TABLE IX-21. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–MERCURY MINES

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Hg	0.001	0.002
Ni	0.1	0.2

*Value in pH units

Levels of Effluent Reduction Attainable. The level of effluent reduction attainable by implementation of BPCTCA is zero discharge of wastewater to surface waters of the U.S.

Subcategory: Mills Recovering Mercury as a Byproduct of Base- or Precious-Metal Concentrates

This subcategory includes operations where mercury is obtained as a byproduct of base- or precious-metal concentrates. The recovery of mercury takes place at a refinery or smelters.

Identification of BPTCA. No separate limitations or technology are proposed. The waste treatment technology and effluent limitations for the appropriate subcategory of baseor precious-metal mills are applicable to this subcategory.

Category: Uranium, Radium, and Vanadium Ores

This category includes mines and mills operated for the extraction or concentration of uranium, radium, and vanadium ores (Vanadium produced as a byproduct from uranium ores). Primary vanadium production is covered, for purposes of this report, under Ferroalloy Ores. It is noted that the suite of treatments used at mines recovering values from igneous rocks differ from but overlaps that used at mines in sedimentary deposits.

Subcategory: Uranium Mines

This subcategory includes all uranium mines, whether open-pit or underground.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is the use of settling ponds in conjunction with lime precipitation, ion exchange (for uranium removal), barium chloride coprecipitation (for radium removal), and secondary settling.

The use of settling ponds is almost universal in this subcategory; however, frequently, the ponds used are small and have inadequate retention time. Where space limitations do not permit use of such ponds, mechanical clarifier-flocculators are acceptable alternatives for settling of suspended solids. Adjustment of wastewater pH prior to discharge may be necessary.

Rationale for Selection. Nearly every uranium mine with wastewater discharge currently practices suspended-solid removal by the use of settling ponds. Treatment, as practiced, is currently uniformly inadequate to achieve acceptable levels of pollutant control.

Currently, in addition to settling ponds, the best treatment employed at uranium mines includes the use of ion exchange for removal of uranium from mine water. This has the dual benefit of effluent treatment plus recovery of uranium values. This treatment has been economically applied for value recovery at concentrations as low as 2 mg/l of uranium.

Treatment, as generally practiced, is judged to be inadequate for removal of either heavy metals or radium concentrations in mine wastewater. The effectiveness of barium chloride coprecipitation has been demonstrated at two mines and two mills in this industry category where it has been shown to reduce radium concentrations to 3 picocuries per liter or less (dissolved). It may be necessary to add sulfate ion (generally obtainable as a waste byproduct from uranium milling) to effect satisfactory coprecipitation. Lime precipitation is in use at facilities in the ore mining and dressing industry and has been demonstrated to be effective for heavy-metal removal. Secondary settling ponds may be necessary for removal of precipitated solids.

Levels of Effluent Reduction Attainable. The parameters selected for control and levels of effluent reduction attainable by use of BPCTCA for this subcategory are presented in Table IX-22. No limitations are proposed for TOC, Mo, and V reductions using BPCTCA.

Subcategory: Mills Processing Uranium Ores by Acid or Alkaline Leaching

This subcategory includes mills processing uranium ores alone, and ores containing both uranium and vanadium, by leaching techniques (whether acid, or alkaline) and associated chemical beneficiation techniques.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is the use of tailings impoundment(s), recycle of process waters, evaporation (where practicable) of wastewater, and, where topography or climate require it, discharge following removal of radium by barium chloride coprecipitation, removal of heavy metals by lime precipitation, settling, and

TABLE IX-22. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–URANIUM MINES

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
COD	100	200
Zn	0.5	1.0
Ra 226 (diss)	3**	10**
Ra 226 (total)	10**	30**
U	2	4

*Value in pH units

†No limitations proposed for BPCTCA

**Value in picocuries per liter

aeration. Mills recovering uranium concentrate by ammonia precipitation can reduce the ammonia concentrations in the discharge and recover portions of the reagent by steam stripping of waste streams from the precipitation stages. Mills using alkaline leach techniques can prevent the build up of radiuim and sulfate ions that may adversely affect the recycling of leaching solutions by separating effluents from the purification, or sodium-removal stages.

Rationale for Selection. Approximately 95 percent of the mills in this subcategory presently impound and evaporate wastewater. However, one mill examined in this study is located in mountainous terrain with limited suitability for the building of evaporation ponds. There are currently no milling operations producing uranium or uranium with vanadium byproduct as their prime product in wet or humid climates. Raw wastes from mills using the acid leaching process remain acid at the process discharge and contain various heavy metals. Acid leach wastes are, therefore, generally not suitable for recycle without additional or specialized treatment. Wastes from the alkaline leaching process require only recarbonization, a normal industry practice, in preparation for recycle, provided that sodium and sulfate ions are either not introduced to or bled off from the recycle loop.

Levels of Effluent Reduction Attainable. The parameters selected for control and levels of effluent reduction attainable by use of BPCTCA for this subcategory are presented in Table IX-23.

Metal Ores, Not Elsewhere Classified

This group of metal-ore operations includes mining and milling of ores of antimony, beryllium, platinum, tin, titanium, rate-earth metals, and zirconium.

Category: Antimony Ores

Subcategory: Antimony-Ore Mines Alone

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is lime precipitation (and sulfide precipitation for antimony removal if necessary) in conjunction with removal of suspended solids by the use of settling impoundments.

To implement the above technology, mechanical clarification devices (e.g., clarifiers, clari-flocculators, etc.) may

TABLE IX-23. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA – URANIUM MILLS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6 to 9*	6 to 9*
TSS	20	30
COD	500	–
NH_3	100	–
As	0.5	1
Mo	†	†
V	†	†
Zn	0.5	1
Ra226 (diss)	3**	10**
Ra226 (total)	10**	30**

*Value in pH units

†No limitations proposed for BPCTCA

**Value in picocuries per liter

also be used. Adjustment of pH by neutralizing agents may be necessary at selected locations prior to discharge. Secondary settling ponds may be necessary for removal of precipitated solids.

Rationale for Selection. Chemical precipitation for removal of heavy metals by lime addition is well-documented and has been well-demonstrated in the ore mining and dressing industry. Sulfide precipitation is the only effective economical method for removal of antimony to low levels. The use of settling impoundments is an almost-universal treatment method for removal of suspended solids. Present treatment methods in use in this subcategory consist of settling alone. Heavy-metal discharges resulting from the use of this treatment alone indicate its uniform inadequacy.

Level of Effluent Reduction Attainable. The parameters selected for control and effluent reduction attainable by use of the above technology in this subcategory are presented in Table IX-24.

Subcategory: Antimony Mills Using Flotation Process

Identification of BPCTCA . The best practicable control technology currently available for this subcategory is zero discharge by impoundment and/or recycle of process wastewater.

To achieve zero discharge by recycling, additional secondary settling of process water may be necessary to reduce slime content. Adequate impoundment area is necessary to achieve zero discharge by impoundment.

Rationale for Selection. The only flotation mill operating for primary-product recovery of antimony is currently achieving zero discharge by impoundment. Recycle of process water, with additional settling treatment for suspended-solid removal should not present any technical difficulty.

Levels of Effluent Reduction Attainable. Zero discharge of process wastewater is attainable by implementation of this technology.

TABLE IX-24. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–ANTIMONY MINES

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
As	0.5	1.0
Fe	1.0	2.0
Sb	0.5	1.0
Zn	0.3	1.0

*Value in pH units

Subcategory: Mills Obtaining Antimony As a Byproduct of Base- or Precious-Metal Milling Operation

This subcategory includes operations where antimony is recovered from a concentrate at a smelter or refinery (antimony extraction plant).

Identification of BPCTCA. No separate limitations are proposed for this subcategory. Limitations developed for the subcategory of the primary metal recovered are recommended for this subcategory.

Category: Beryllium Ores

Subcategory: Beryllium Mines

Identification of BPCTCA. The best practicable control technology currently available is zero discharge by impoundment of mine wastewater.

Rationale for Selection. The single operating mine in this subcategory is achieving zero discharge by impoundment.

Levels of Effluent Reduction Attainable. Zero discharge of mine wastewater is attainable by implementation of this technology.

Subcategory: Beryllium Mills

Identification of BPCTCA. The best practicable control technology currently available is the total impoundment of process wastewater.

Rationale for Selection. The above technology is currently practiced at the single beryllium mill now operating.

Levels of Effluent Reduction Attainable. Zero discharge of process wastewater is attainable by implementation of this technology.

Category: Platinum Ores

This category represents facilities operated for the mining and concentration of platinum ores by gravity-separation methods. Most platinum in the U.S. is obtained as a byproduct of smelting and refining of base or precious metals. A single operating facility currently obtains platinum concentrates by dredging and gravity separation for concentration of platinum and a small amount (3 to 4 percent of concentrates) of byproduct gold.

Identification of BPCTCA. The best practicable control technology currently available is the use of settling ponds for control of suspended-solid levels.

An alternative to implementation of this technology is the pumping of wastewater back over tailings for sand and gravel filtration, but a settling impoundment of some type will be required for primary settling before discharge.

Rationale for Selection. The single operating facility of this type currently employs settling ponds and filtration through sands prior to discharge. Therefore, no additional costs will be incurred.

Levels of Effluent Reduction Attainable. The parameters chosen for control and the levels of effluent reduction attainable for this category are presented in Table IX-25.

Subcategory: Rare-Earth Ores

Subcategory: Mines Operated for Obtaining Primary or Byproduct Rare Earth Ores

This subcategory is represented by one rare-earth mine, which currently has no discharge of mine water.

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is zero discharge by impoundment and/or reuse of mine water as process water in a mill.

Rationale for Selection. Currently, no rare-earth-ore mines exist which discharge wastewater. An operation located in the arid region of the U.S. might practice total impoundment should mine wastewater be encountered.

Levels of Effluent Reduction Attainable. Zero discharge of pollutants can be attained should mine wastewater result.

Subcategory: Rare Earth Ore Mills Using Flotation or Leaching Process

This subcategory includes a single operation extracting rareearth metals from rare-earth ores by means of a flotation and leaching process.

TABLE IX-25. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–PLATINUM MILLS AND MINES USING GRAVITY SEPARATION METHODS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	30	50

*Value in pH units

Identification of BPCTCA. The best practicable control technology currently available for this subcategory is zero discharge by separation of waste streams, followed by impoundment and evaporation of leaching-process wastewater and recycle of flotation-process water from a sedimentation impoundment.

Rationale for Selection. The single operating facility in this subcategory is currently practicing BPCTCA.

Levels of Effluent Reduction Attainable. Zero discharge of process-water effluent is attainable by this technology.

Subcategory: Mills or Mine/Mills Obtaining Rare Earth Minerals by Gravity Methods

The rare-earth mineral monazite is currently recovered as a byproduct of placer operations for titanium minerals. BPCTCA for this subcategory is covered under the appropriate titanium-ore subcategory. No separate or additional limitations are proposed.

Category: Tin Ores

Currently, tin is primarily recovered at one location in the U.S. as a byproduct of molybdenum mining and milling. A small amount of tin is also produced at dredging operations for gold as a byproduct of placer mining in Alaska, and a placer operation in New Mexico. and the levels of effluent reduction attainable are covered under the appropriate ferroalloy-ore or gold-ore subcategory.

Although tin is recovered by placer and gravity methods as well as by magnetic and electrostatic separation or extraction, no major deposits are currently exploited in the U.S.

Cagegory: Titanium Ores

Subcategory: Titanium Mines

Currently in the U.S., there is one operation mining a titanium-ore deposit by open-pit methods.

Identification of BPCTCA. The best practicable control technology currently available is neutralization in conjunction with the use of a settling pond for suspended solid removal. pH adjustment prior to discharge of wastewater may be necessary.

Rationale for Selection. Current practice in the single operating facility is impoundment and discharge of mine wastewater. Retention time for this small settling pond is short, and treatment for suspended solids in the discharge water is inadequate. Expansion of the settling pond to allow increased retention time is necessary. Neutralization of mine waters is necessary to maintain pH values at levels which will prevent solubilization of heavy metals.

Levels of Effluent Reduction Attainable. The parameters selected and levels of effluent reduction attainable by use of the above technology are presented in Table IX-26.

Subcategory: Titanium Mills or Mine/Mills Using Electrostatic and/or Magnetic plus Gravity and/or Flotation Methods

This subcategory is currently represented by one milling operation, which concentrates ilmenite from an ilmenite/ magnetite ore.

Identification of BPCTCA. The best practicable technology currently available is the use of tailing ponds with lime precipitation adjustment of wastewater pH prior to discharge may be necessary of process water.

Rationale for Selection. Currently, the one operating mill in this subcategory is practicing impoundment and recycle during approximately ten months of the year. Lime precipitation is well-documented and has been well-demonstrated in other segments of the ore mining and dressing industry, and its use is necessary to reduce heavy-metal concentrations in discharge water.

Levels of Effluent Reduction Attainable. The parameters selected for control and the levels of effluent reduction attainable by use of the above technology are presented in Table IX-27.

Subcategory: Titanium Dredge Mine With Wet Separation

This subcategory includes operations engaged in the dredge mining of placer deposits of sands containing rutile, ilmenite, and leucoxene. Monazite, zircon, and other heavy minerals are also obtained as byproducts from these operations. Milling techniques employed in this subcategory include the use of wet gravity methods in conjunction with electrostatic and/or magnetic methods.

TABLE IX-26. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–TITANIUM MINES

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Fe	1.0	2.0

*Value in pH units

TABLE IX-27. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–TITANIUM MILLS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Fe	0.1	0.2
Ni	0.1	0.2
Zn	0.5	1.0

*Value in pH units

Identification of BPCTCA. The best practicable control technology currently available for this category is settling impoundment with maintenance of a pH of 3.5, secondary settling, and neutralization.

Current practice of this technology normally involves the use of three sedimentation ponds. The first pond is maintained at acid pH (3.5) for control of organic matter. Secondary settling is practiced at the second pond, with a third "polishing pond" being used for final clarification and neutralization by lime addition.

Rationale for Selection. Three operations are currently practicing this technology, and it has been demonstrated effective for reduction of COD resulting from humic materials present in the process wastewater. Suspended-solid levels are maintained at low values due to the use of three settling ponds.

Levels of Effluent Reduction Attainable. The parameters selected for control and the levels of effluent reduction attainable by use of the above technology are presented in Table IX-28.

Category: Zirconium Ores

Zircon is produced as a byproduct of titanium placer operations. Mining and milling methods are inseparable from those used in titanium dredge mining and wet milling. As a result, no separate technology or limitations are proposed for zirconium ores.

TABLE IX-28. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BPCTCA–TITANIUM DREDGE MINE WITH WET SEPARATION MILL

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6[†] to 9[†]	6[†] to 9[†]
TSS	20	30
COD	50	–
Fe	1.0	2.0

[†] Value in pH units

SECTION X

BEST AVAILABLE TECHNOLOGY ECONOMICALLY ACHIEVABLE, GUIDELINES AND LIMITATIONS

INTRODUCTION

The effluent limitations which must be achieved by July 1, 1983 are based on the degree of effluent reduction attainable through the application of the best available technology economically achievable (BATEA). For the ore mining and dressing industry, this level of technology was based on the very best control and treatment technology employed by a specific point source within each of the industry's subcategories, or which is readily transferable from one industry process to another. In Section IV, the ore mining and dressing industry was initially divided into ten major categories. Several of those major categories have been further subcategorized, and, for reasons explained in Section IV, each subcategory will be treated separately for the recommendation of effluent limitations guidelines and standards of performance. As also explained in Section IV, the subcategories presented in this section will be consolidated, where possible, in the regulations derived from this development document.

The following factors were taken into consideration in determining the best available technology economically achievable:

(1) age of equipment and facilities involved;
(2) process employed;
(3) engineering aspects of the application of various types of control techniques;
(4) process changes;
(5) cost of achieving the effluent reduction resulting from application of BATEA; and
(6) nonwater-quality environmental impact (including energy requirements).

In contrast to the best practicable control technology currently available, best available technology economically achievable assesses the availability in all cases of in-process controls as well as control or additional treatment techniques employed at the end of a production process. In-process control options available which were considered in establishing these control and treatment technologies include:

(1) alternative water uses
(2) water conservation
(3) waste-stream segregation
(4) water reuse
(5) reuse of wastewater constituents
(6) waste treatment
(7) good housekeeping
(8) preventive maintenance
(9) quality control (raw material, product, and effluent)
(10) monitoring and alarm systems.

Those plant processes and control technologies which, at the pilot plant, semi-works, or other level, have demonstrated both technological performances and economic viability at a level sufficient to reasonably justify investing in such facilities were also considered in assessing the best available technology economically achievable. Although economic factors are considered in this development, the costs for this level of control are intended to be for the top-of-the-line of current technology subject to limitations imposed by economic and engineering feasibility. However, this technology may necessitate some industrially sponsored development work prior to its application.

Based upon the information contained in Sections III through IX of this report, the following determinations were made on the degree of effluent reduction attainable with the application of the best available technology economically achievable in the various categories and subcategories of the ore mining and dressing industry.

GENERAL WATER GUIDELINES

Process Water

Process water is defined as any water contacting the ore, processing chemicals, intermediate products, byproducts, or products of a process, including contact cooling water. All process-water effluents are limited to the pH range of 6.0 to 9.0 unless otherwise specified.

Cooling Water

In the ore mining and dressing industry, cooling and process waters are sometimes mixed prior to treatment and discharge. In other situations, cooling water is discharged separately. Based on the application of best available technology economically achievable, the recommendations for the discharge of such cooling water are:

An allowed discharge of all non-contact cooling waters provided that these conditions are met:

(1) Thermal pollution be in accordance with standards to be set by EPA policies. Excessive thermal rise in once-through, non-contact cooling water in the ore mining and dressing industry has not been a significant problem.

(2) All non-contact cooling waters be monitored to detect leaks of pollutants from the process. Provisions should be made for treatment to the standards established for the process-wastewater discharges prior to release in the event of such leaks.

(3) No untreated process waters be added to the cooling waters prior to discharge.

The above non-contact cooling-water recommendations should be considered as interim, since this type of water plus blowdown for water treatment, boilers, and cooling towers will be regulated by EPA at a later date as a separate category.

Storm-Water Runoff

Storm water runoff may present pollution control problems whenever the runoff passes over an area disturbed by the ore mining operation or the ore dressing operation, where there are stock piles of ore to be processed or where waste materials are stored.

Facilities should be designed to treat or contain this runoff, however, regardless of the size of the treatment facility, there are natural occurrences which might result in the system being overloaded with the resultant discharge violating the effluent limitations set forth in this section. To provide guidance to be used in the design of a treatment system and to avoid the legal problems that might result if an unauthorized discharge occurs, the following provisions are recommended:

Any untreated overflow which is discharged from facilities designed, constructed and operated to contain all process generated wastewater and the surface runoff to the treatment facility, resulting from a 25-year, 24-hour precipitation event and which occurs during or directly as a result of a precipitation event shall not be subject to the limitations set forth in this section.

The term "25-year, 24-hour precipitation event" means the maximum 24-hour precipitation event with a probable reoccurrence of once in 25 years as defined by the National Weather Service and Technical Paper No. 40, "Rainfall Frequency Atlas of the U.S.,: May 1961 and subsequent amendments or equivanlent regional or rainfall probability information developed therefrom. It is intended that when subsequent events occur each of which results in less precipitation than would occur during a "25-year, 24-hour precipitation event," that result in an equivalent amount of runoff, the same provisions will apply.

BEST AVAILABLE TECHNOLOGY ECONOMICALLY ACHIEVABLE, BY ORE CATEGORY AND SUBCATEGORY

Category: Iron Ores

Subcategory: Iron-Ore Mines

Identification of BATEA. The best available technology ecomically achievable for the wastewater resulting from the mining of iron ore is the use of settling ponds with coagulation/ flocculation systems in conjunction with chemical precipitation by lime to a pH of 8.5 to 9.

To implement the above technology, secondary settling may be required for removal of precipitated solids.

Rationale for Selection. The use of lime neutralization and precipitation has been well-demonstrated in the ore mining and dressing industry, as well as in the coal mining industry, where it is used for control of acid mine drainage and for precipitation of metals. Application of this technology in the bauxite mining industry has been well-documented, both on a full-scale basis and on a pilot scale.

Levels of Effluent Reduction Attainable. The parameters selected for control and the levels of effluent reduction attainable by the use of this technology are presented in Table X-1.

TABLE X-1. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BATEA–IRON-ORE MINES

PARAMETER	CONCENTRATION (mg/ℓ)	
	30-day average	daily maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Dissolved Fe	0.5	1.0

*Value in pH units

Subcategory: Iron Ore Mills Employing Physical and Chemical Separation And Mills Using Only Physical Separation (Magnetic and Non-Magnetic)

Identification of BATEA. The best available technology economically achievable for the treatment of wastewater resulting from milling processes used in this subcategory is the use of tailing impoundments with coagulation/flocculation systems in conjunction with chemical precipitation by lime addition to a pH of 8.5 to 9.

To implement the above technology, secondary settling ponds may be required for removal of precipitated solids. Treatment requirements can be substantially reduced by partial recycling of process water, a practice which has widespread use in this subcategory. Adjustment of wastewater pH prior to discharge may be necessary.

Rationale for Selection. The use of lime neutralization and precipitation has been well-demonstrated in the ore mining and dressing industry, as well as in the coal mining and bauxite mining industries, where it has been used extensively for control of acid mine drainage and heavy-metal removal.

Levels of Effluent Reduction Attainable. The parameters selected for control and the levels of effluent reduction attainable by application of BATEA are presented in Table X-2.

Subcategory: Iron-Ore Mills Employing Magnetic and Physical Separation (Mesabi Range)

Identification of BATEA. The best available technology economically achievable for this subcategory is zero discharge of process wastewater. (Same as BPCTCA.)

Category: Copper Ores

Subcategory: Copper-Ore Mines

Identification of BATEA. The best available technology economically achievable for this subcategory is the use of lime precipitation and settling or clarification aided by flocculant addition if necessary. This is essentially the same as BPCTCA; however, by optimum pH control and more efficient operation of the system, the recommended levels can be obtained.

TABLE X-2. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BATEA–IRON-ORE MILLS EMPLOYING PHYSICAL METHODS AND CHEMICAL SEPARATION AND ONLY EMPLOYING PHYSICAL SEPARATION

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Dissolved Fe	0.5	1.0

*Value in pH units

Rationale for Selection. The treatment of wastewater by lime precipitation with optimum pH control is well documented and currently in use in the ore mining and dressing industry.

Levels of Effluent Reduction Attainable. The parameters selected and levels of effluent reduction attainable are presented in Table X-3.

Subcategory: Copper-Ore Mines Employing Hydrometallurgical Processes

Identification of BATEA. The best available technology economically achievable is zero discharge of hydrometallurgical process wastewater. (Same as BPCTCA.)

Subcategory: Copper Mills Employing Vat-Leaching Process

Identification of BATEA. The best available technology economically achievable is zero discharge of process wastewater. (Same as BPCTCA.)

Subcategory: Copper Mills Employing Froth Flotation

Identification of BATEA. The best available technology economically achievable for this subcategory is zero discharge of process wastewater through the reuse, recycle, and evaporation of all process waters.

Rationale for Selection. The procedures which can be employed at flotation mills in this subcategory for recycling are presently being demonstrated in the copper milling industry.

> Segregation of Wastewater: Water conveyed to a mill treatment system from mine pumpout may result in excess water and, thus, a discharge. Where this occurs, separate treatment of mine water may be necessary to reduce the amount of water to be impounded and to improve the water balance for a recycle system. Evaporation ponds for a portion of wastewater may be employed seasonally to reduce wastewater volume.
>
> Recycle of Process Water: Process water should be recycled from impoundments. Makeup water can be added, when necessary, to maintain the needed volume of process water.

TABLE X-3. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BATEA—COPPER MINES

PARAMETER	CONCENTRATION (mg/ ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Cu	0.05	0.1
Pb	0.1	0.2
Hg	0.001	0.002
Zn	0.5	1.0

*Value in pH units

Tailing-Pond Seepage: Seepage, where it occurs, should be diverted to a ditch and pumped back into the tailing pond.

Current operations in this subcategory employ partial or complete recycle of process water. Application of methods for reduction of wastewater flow, and recycle of process water, will enable the zero-discharge limitation to be met.

Levels of Effluent Reduction Attainable. Zero discharge of process wastewater is attainable by the implementation of this technology.

Category: Lead and Zinc Ores

Subcategory: Lead and Zinc Mines

Identification of BATEA. The best available technology economically achievable for this subcategory is the use of lime precipitation and settling or clarification aided by flocculant addition if necessary. This is essentially the same as BPCTCA; however, by optimum pH control and more efficient operation of the system, the recommended levels can be obtained.

Rationale for Selection. The treatment of wastewater by lime precipitation with optimum pH control is well documented and currently in use in the ore mining and dressing industry.

Levels of Effluent Reduction Attainable. The parameters selected and levels of effluent reduction attainable are presented in Table X-4.

Subcategory: Lead and Zinc Mills

Identification of BATEA. The best available technology economically achievable is zero discharge through total recycle and impoundment of process water.

To implement this technology. Segregation and treatment of mine water separately from process water may be necessary at some locations because of an excess water balance adversely affecting the ability to impound.

Rationale for Selection. The fact that several lead/zinc and copper sulfide ore mills do operate in a total-recycle mode suggests that zero discharge is an attainable mode of operation for all such mills. The technological feasibility

TABLE X-4. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BATEA–LEAD AND ZINC MINES

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Cu	0.05	0.1
Hg	0.001	0.002
Pb	0.1	0.2
Zn	0.5	1.0

*Value in pH units

of recycle at lead/zinc/copper (sulfide-mineral) mills has been demonstrated and, with adequate development work, should be applicable to all mill operations. In some cases, engineering modifications--and, perhaps alternative modes of solids disposal and retention--would appear to provide feasible solutions to water-balance problems. For example, dewatering of tailings in a clarifier with recirculation of the overflow may be necessary where precipitation presently creates difficulty for total recycle and impoundment.

Levels of Effluent Reduction Attainable. Zero discharge of effluent will result from implementation of BATEA.

Category: Gold Ores

Subcategory: Gold Mines (Alone)

Identification of BATEA. The best available technology economically achievable for this subcategory is the use of lime precipitation and settling or clarification aided by flocculant addition if necessary. This is essentially the same as BPCTCA; however, by optimum pH control and more efficient operation of the system, the recommended levels can be obtained.

Rationale for Selection. The treatment of wastewater by lime precipitation with optimum pH control is well documented and currently in use in the ore mining and dressing industry.

Levels of Effluent Reduction Attainable. The parameters selected and levels of effluent reduction attainable are presented in Table X-5.

Subcategory: Gold Mines or Mine/Mills Employing Amalgamation

Identification of BATEA. The best available technology economically achievable is zero discharge of process water by a process change to cyanidation extraction, settling pond treatment, and recycle of decant water.

To implement this technology, a higher degree of control over the quality of the reclaimed water can be maintained if the tailing-pond decant is collected in a secondary or polishing pond prior to recycle back to the mill circuit.

Rationale for Selection. The BATEA identified for this subcategory has demonstrated application and reliability in

TABLE X-5. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BATEA–GOLD MINES

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Cu	0.05	0.1
Hg	0.001	0.002
Pb	0.1	0.2
Zn	0.5	1.0

*Value in pH units

the gold milling industry. Total recycle of tailing-pond decant is currently practiced by one mill. Total-recycle systems are also being employed in several other milling subcategories. The change in process from amalgamation to cyanidation will entail engineering modifications. The feasibility of this process change is demonstrated by the recent change of a gold mill from amalgamation to cyanidation.

Levels of Effluent Reduction Attainable. Zero discharge of process wastewater is attainable by implementation of this technology.

Subcategory: Gold Mills or Mine/Mills Employing Cyanidation

Identification of BATEA. The best available technology economically ahcievable in this subcategory is no discharge of process wastewater by impoundment or complete recycle of process wastewater. (Same as BPCTCA).

Subcategory: Gold Mills Employing Froth Flotation Process

Identification of BATEA. The best available technology economically achievable for this subcategory is zero discharge by impoundment and recycle of process water.

The recommended technology is essentially the same as BPCTCA except that engineering modifications of the process-water system are designed for total recycle and impoundment.

Rationale for Selection. The single operating facility in this subcategory currently is achieving zero discharge, nine to ten months of the year, by prevention of runoff entry into tailing impoundments, increased impoundment volume, and total recycle of process water. Optimization of the existing system by minor modifications and engineering changes should enable attainment of zero discharge.

Levels of Effluent Reduction Attainable. Zero discharge of process wastewater is attainable by implementation of this technology.

Subcategory: Gold Mills or Mines Employing Gravity Separation

Identification of BATEA. The best available technology economically achievable is the use of settling or tailing impoundments. (Same as BPCTCA.)

Subcategory: Mill Operations Where Gold is Recovered as Byproduct of Base Metal Milling Operation

Identification of BATEA. No separate limitations are recommended for this subcategory. The BATEA for this subcategory is the same as BATEA for the primary metal recovered.

Category: Silver Ores

Subcategory: Silver Mines (Alone)

Identification of BATEA. The best available technology economically achievable for this subcategory is the use of lime precipitation and settling or clarification aided by flocculant addition if necessary. This is essentially the same as BPCTCA; however, by optimum pH control and more efficient operation of the system, the recommended levels can be obtained.

Rationale for Selection. The treatment of wastewater by lime precipitation with optimum pH control is well documented and currently in use in the ore mining and dressing industry.

Levels of Effluent Reduction Attainable. The parameters selected and levels of effluent reduction attainable are presented in Table X-6.

Subcategory: Silver Mills Employing Froth Flotation

Identification of BATEA. The best available technology economically achievable is zero discharge by use of total recycle of process water and/or total impoundment.

Rationale for Selection. Currently, two silver mills are recycling their process water. One mill reclaims all of its tailing pond decant while the second presently reclaims 60 percent of its tailing pond decant. Recycle of all process water is currently technically achievable, by engineering modifications of the process water system designed for total recycle and impoundment. The technical feasibility of achieving no discharge is discussed in detail in Section VII.

TABLE X-6. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BATEA–SILVER MINES (ALONE)

PARAMETER	CONCENTRATION (mg/ ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Cu	0.05	0.1
Hg	0.001	0.002
Pb	0.1	0.2
Zn	0.5	1.0

*Value in pH units

Levels of Effluent Reduction Attainable

Zero discharges of process wastewater is attainable by implementation of this technology.

Subcategory: Silver Mills or Mine/Mills Using Cyanidation

Identification of BATEA. The best available technology economically achievable is attainment of zero discharge by total recycle and/or total impoundment of process wastewater. (Same as BPCTCA.)

Subcategory: Silver Mills or Mine and Mills Using Amalgamation

Identification of BATEA. The best available technology economically achievable for this subcategory is the attainment of zero discharge by a process change to cyanidation and total recycle and/or total impoundment of process wastewater.

In order to achieve total recycle, a higher degree of control over the quality of the reclaim water can be maintained if the tailing-pond decant is collected in a secondary settling, or polishing, pond prior to recycle back to the mill circuit. The secondary pond will serve as the surge pond in the recycle system.

Rationale for Selection. The recommended technology has been demonstrated as feasible in both the gold and silver milling industries. Recycle systems are also being employed in the copper, lead, and zinc milling industries. Process modification from amalgamation to cyanidation has been technically accomplished in the gold milling industry with no apparent loss of recovery and with elimination of high mercury levels in the discharge.

Levels of Effluent Reduction Attainable. No discharge of process wastewater is attainable by implementation of the above technology.

Subcategory: Silver Mills Using Gravity Separation Methods

Identification of BATEA. The best available technology economically achievable is the use of settling impoundment. (Same as BPCTCA.)

Subcategory: Mill Operations where Silver is Recovered as Byproduct of Base-Metal Milling Operation

Identification of BATEA. No separate limitations are recommended for this subcategory. The BATEA for this subcategory is the same as BATEA for the primary metal recovered.

Category: Bauxite Ores

Identification of BATEA. The best available technology economically achievable for this subcategory is use of lime precipitation and settling with optimized pH control and operating efficiencies.

Rationale for Selection. The recommended treatment is currently being operated at one bauxite operation with no technical difficulties. Although relatively low flow conditions prevail, a large-scale treatment plant is currently under construction and is expected to be operational in mid-1975.

Levels of Effluent Reduction Attainable. The parameters selected and effluent limitations attainable by implementation of this technology are presented in Table X-7.

Category: Ferroalloy Ores

Subcategory: Ferroalloy Mines Producing Greater Than 5,000 Metric Tons (5512 Short Tons) Per Year

Identification of BATEA. The best available technology economically achievable is use of lime precipitation in conjunction with a settling pond and the use of flocculants and secondary settling. Addition of lime prior to removal of suspended solids is desirable.

In selected instances, the use of coprecipitation by ferric sulfate, or ion exchange, for removal of molybdenum may be necessary. An alternative method for suspended-solid removal is the use of a mechanical clari-flocculator.

Rationale for Selection. The use of chemical flocculants and secondary settling is a common practice in the ore mining and dressing industry and has been demonstrated effective. The limitations on molybdenum are met at existing mines by the practice of sound water management within the mine (preventing contact with finely divided

TABLE X-7. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BATEA—BAUXITE MINES (ACID OR ALKALINE MINE DRAINAGE)

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Al	1.0	2.0
Fe	0.5	1.0
Zn	0.1	0.2

*Value in pH units

ore). The removal of molybdenum by coprecipitation or ion exchange is currently being practiced at a pilot plant and on the laboratory scale.

Levels of Effluent Reduction Attainable. The parameters selected and levels of effluent reduction attainable are presented in Table X-8.

Subcategory: Ferroalloy Mills or Mines and Mills Processing Less than 5,000 Metric Tons (5,512 Short Tons) per Year (other than Ore Leaching)

Identification of BATEA. The best available technology economically achievable is the use of settling or tailing ponds in conjunction with neutralization. (Same as BPCTCA.)

Subcategory: Mills Processing More Than 5,000 Metric Tons (5,512 Short Tons) of Ferroalloy Ores per Year By Physical Methods

Identification of BATEA. The best available technology economically achievable is the addition of total process water recycle to BPCTCA (partial recycle, lime precipitation, tailing pond, flocculation, and secondary settling).

Rationale for Selection. There are no technical obstacles to process-water recycle at these operations. Effective suspended solid removal precludes deleterious effects from circulating slimes on recovery. At certain locations, total recycle with zero discharge might be employed, eliminating the need for lime precipitation.

Levels of Effluent Reduction Attainable. The parameters selected and effluent reduction attainable by implementation of this technology are presented in Table X-9.

Subcategory: Mills Processing More Than 5,000 Metric Tons (5,512 Short Tons) of Ferroalloy Ores per Year By Flotation Methods

Identification of BATEA. The best available technology economically achievable is the addition of process-water recycle, oxidation (aeration, chlorination, or ozonation), and coprecipitation or ion exchange.

Rationale for Selection. The use of recycle to reduce the volume of water discharged, and the employment of treatment processes aimed specifically at the removal of COD, cyanide,

TABLE X-8. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BATEA–FERROALLOY-ORE MINES PRODUCING > 5000 METRIC TONS (5,512 SHORT TONS) PER YEAR.

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
As	0.5	1.0
Cd	0.05	0.1
Cu	0.05	0.1
Mo	2.0	4.0
Pb	0.1	0.2
Zn	0.1	0.2

*Value in pH units

TABLE X-9. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BATEA–FERROALLOY-ORE MILLS PROCESSING MORE THAN 5,000 METRIC TONS (5,512 SHORT TONS) PER YEAR BY PHYSICAL METHODS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
As	0.5	1.0
Cd	0.05	0.1
Cu	0.05	0.1
Mo	2.0	4.0
Zn	0.1	0.2

*Value in pH units

and molybdenum, will effect substantial reduction in total pollutant load discharged from operations in this subcategory. Treatment technology is drawn from pilot-plant studies and examples of waste treatment in other industries, as well as from other segments of the ore mining and milling industry. In some cases, substantial process development and optimization effort will be required for the successful application of selected treatment technology in the ferroalloy-ore mining and milling industry.

As discussed in Section IX, recycle can be difficult to apply successfully in flotation operations--particularly, in fatty-acid floats. Nonetheless, the industry affords numerous examples of operations successfully practicing a high degree of water reuse. Although simple sulfide-float circuits are found to be most compatible with recycle, examples of recycle may be cited even in plants with complex fatty-acid flotation circuits. Auxiliary techniques such as aeration may be required to limit problems with recirculating reagents, and, since some floats are found to be sensitive to inorganic salts in the water, a certain amount of bleed from some float circuits is expected to be necessary. For some flotation circuits, extensive development is expected to be required to achieve stable operation with recycled water. Based on what has been achieved in the industry to date, discharge of 25 percent or less of process-water volume can be achieved. Zero discharge may be attained by use of total recycle of process water and/or by impoundment, at selected sites.

The oxidation of cyanide ion to cyanate (and, ultimately, carbon dioxide and nitrate) and aeration for the reduction of COD are standard treatment practices in a variety of other industries which are applicable to flotation-mill effluents. Since raw waste values of both cyanide and COD are relatively low, a simple aeration or ozonation or chlorination treatment will be effective. Such treatment must, of course, follow removal of particulates and oxidizable species, such as metal sulfides, from the waste stream. Data for existing operations indicate that, for many sites, this treatment may be rendered unnecessary by proper reagent control and oxidization incidental to other treatment.

Two techniques for the removal of molybdenum from solution which are currently in the pilot-plant stage hold promise for large-scale application and provide the basis for 1983 effluent limitations. Coprecipitation with ferric hydroxide by ferric sulfate addition, and ion exchange, both have been shown to be viable, although not presently optimized, techniques. A considerable history of unintentional collection (and subsequent rejection) of molybdenum in ion-exchange uranium-recovery operations provides background for the application of that technique. Coprecipitation has been studied extensively as part of an examination of the potential pollutions associated with molybdenum.

Levels of Effluent Reduction Attainable. The parameters selected and effluent reduction attainable by implementation of the above technology are presented in Table X-10.

Subcategory: Mills Processing Ferroalloy Ores By Leaching Techniques

Identification of BATEA. The best available technology economically achievable is the addition of further waste segregation, air stripping, chromium reduction, and aeration (to reoxygenate wastewater after chromium removal) to BPCTCA (lime precipitation, primary and secondary settling, flocculation, and wastewater segregation).

Rationale for Selection. Segregation of waste streams from solvent-extraction/precipitation circuits is currently practiced at one site in the ferroalloy milling industry, where concentrates are leached. This allows treatment of the segregated waste stream for TDS removal by evaporation and crystallization, and for removal of ammonia in an air stripper. Air and steam stripping for ammonia removal are currently practiced in several related industries and at one site in the ferroalloy-ore mining and dressing industry.

The use of sulfur dioxide for reduction of hexavalent chromium to trivalent forms, with subsequent precipitation of the hydroxide, is a standard waste-treatment practice in many industries. Application to milling wastes will require process optimization for lower initial chromium concentrations but does not present any insurmountable problems.

Other treatment techniques which may be used on these waste streams have been discussed under previous subcategories and pose no special problems in treating leaching-mill waste water. The feasibility of process-water recycle will be highly variable, depending on the details of specific operations, amount of soluble material in the ore, leaching reagents, eluents, precipitants, etc. Zero discharge may be achieved at specific sites.

TABLE X-10. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BATEA–FERROALLOY-ORE MILLS USING FLOTATION PROCESS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
COD	25	50
Cyanide	0.02	0.04
As	0.5	1.0
Cd	0.05	0.1
Cu	0.05	0.1
Mo	2.0	4.0
Zn	0.1	0.2

*Value in pH units

Levels of Effluent Reduction Attainable. The parameters selected and effluent reduction attainable for this subcategory are presented in Table X-11.

Category: Mercury Ores

Subcategory: Mercury Mines

Identification of BATEA. The best available technology economically achievable is the use of chemical (lime or sulfide) precipitation and settling impoundments.

Rationale for Selection

The recommended technology is essentially the same as BPCTCA except that the use of sulfide ion as a precipitant for removal of heavy metals (mercury in particular) accomplishes more complete removal.

Levels of Effluent Reduction Attainable. The levels of effluent reduction attainable through the use of the above technology are presented in Table X-12.

Subcategory: Mercury Mills or Mine/Mills Employing Gravity Separation

Identification of BATEA. The best available technology economically achievable is zero discharge by recycle of process water and/or total impoundment. (Same as BPCTCA.)

Subcategory: Mercury Mills or Mine/Mills Using Flotation Process

Identification of BATEA. The best available technology economically achievable is zero discharge by the use of total recycle and/or total impoundment of process wastewater. (Same as BPCTCA.)

Subcategory: Mills Recovering Mercury as a Byproduct of Base- or Precious-Metal Concentrates Identification of BATEA. No separate limitations or technology are proposed. The BATEA for this subcategory is the same as BATEA for the primary base or precious metal recovered.

TABLE X-11. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BATEA–FERROALLOY-ORE MILLS USING LEACHING PROCESS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Ammonia	50	100
As	0.5	1.0
Cd	0.05	0.1
Cr	0.05	0.1
Cu	0.15	0.30
Zn	0.1	0.2

*Value in pH units

TABLE X-12. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BATEA – MERCURY MINES

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
Hg	0.0005	0.001
Ni	0.1	0.2

*Value in pH units

Category: Uranium, Radium, and Vanadium Ores

Subcategory: Uranium Mines

Identification of BATEA. The best available technology economically achievable is the use of BPCTCA technology in conjunction with sulfide precipitation, ion exchange for Mo removal, ferrous sulfate coprecipitation for V removal, and aeration.

Rationale for Selection. The use of sulfide precipitation for removal of heavy metals has been demonstrated in the chloralkalai industry, as well as in numerous pilot- and bench-scale experimental treatment systems. Relatively simple, inexpensive systems are available for use in implementing this treatment. Ion-exchange technology has been demonstrated in the uranium industry as effective in extraction of uranium values from mine or process water. Ion-exchange resins are available which are specific for the ions involved. Coprecipitation of vanadium, as discussed in Section VII, is capable of removing this waste parameter to below the levels specified. Aeration of wastewater will assist in raising dissolved oxygen levels and in lowering of COD.

Levels of Effluent Reduction Attainable. The parameters selected for control and the effluent reductions attainable by implementation of this technology are presented in Table X-13.

Subcategory: Mills Processing Uranium Ores by Acid or Alkaline Leaching

Identification of BATEA. The best available technology economically achievable is zero discharge by the use of impoundment and evaporation and/or recycle.

Rationale for Selection. Approximately 95% of the operations contained in this subcategory achieve zero discharge by either of two methods: impoundment and evaportation alone or impoundment, evaporation and recycle. Raw wastewater from mills using acid leaching remains acid at the process discharge, retains various heavy metals and generally is not suitable for recycling without additional or specialized treatment. Wastewater from the alkaline-leach process is normally recycled in part. There is one known acid-leach milling operation, located in Colorado, which routinely discharges its wastewater.

TABLE X-13. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR BATEA–URANIUM MINES

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
COD	50	100
As	0.5	1.0
Cd	0.05	0.1
Mo	2.0	4.0
V	5	10
Zn	0.1	0.2
Ra 226 (diss)	3†	10†
Ra 226 (total)	10†	30†
U	2	4

*Values in pH units

†Values in picocuries per liter

Levels of Effluent Reduction Attainable. Zero discharge of process wastewater is attainable by implementation of the above technology.

Metal Ores, Not Elsewhere Classified

Category: Antimony Ores

Subcategory: Antimony-Ore Mines (Alone)

Identification of BATEA. The best available technology economically achievable for this subcategory is chemical (lime and sulfide) precipitation in conjunction with settling impoundments. (Same as BPCTCA.)

Subcategory: Antimony Mills Using Flotation Process

Identification of BATEA. The best available technology economically achievable is zero discharge by impoundment and/or recycle of process wastewater. (Same as BPCTCA.)

Subcategory: Mills Obtaining Antimony As a Byproduct of Base- or Precious-Metal Milling Operation

Identification of BATEA. No separate limitations are proposed for this subcategory. Limitations developed for the subcategory of the primary metal recovered are recommended for this subcategory.

Category: Beryllium Ores

Subcategory: Beryllium Mills

Identification of BATEA. The best available technology economically achievable is zero discharge by total impoundment of process wastewater. (Same as BPCTCA.)

Category: Platinum Ores

Identification of BATEA. The best available technology economically achievable is the use of settling ponds. (Same as BPCTCA.)

Category: Rare-Earth Ores

Subcategory: Mines Operated For Obtaining Primary or Byproduct Rare-Earth Ores

Identification of BATEA. The best available technology economically achievable is zero discharge by impoundment or reuse of mine water as process water in a mill. (Same as BPCTCA.)

Subcategory: Rare Earth Ore Mills Using Flotation or Leaching Process

Identification of BATEA. The best available technology economically achievable is zero discharge by separation of waste streams, followed by impoundment and evaporation of leaching-process wastewater and recycle of flotation-process water from a sedimentation impoundment. (Same as BPCTCA.)

Subcategory: Mills or Mine Mills Obtaining Rare Earth Minerals By Gravity Methods

BATEA for this subcategory is covered under the appropriate titanium-ore subcategory. No separate limitations are proposed.

Category: Tin Ores

No separate limitations are proposed for this category.

Category: Titanium Ores

Subcategory: Mines Obtaining Titanium Ore By Lode Mining

Identification of BATEA. The best available technology economically achievable is neutralization in conjunction with a settling pond for suspended-solid removal. (Same as BPCTCA.) Maintenance of an alkaline pH will prevent solubilization of heavy metals and reduce their concentration in the discharge waters.

Subcategory: Titanium Mills or Mine/Mills Using Electrostatic and/or Magnetic plus Gravity and/or Flotation Methods

Identification of BATEA. The best available technology economically achievable is zero discharge by tailing-pond treatment and total recycle of the tailing-pond decant. In addition, a small secondary pond may be necessary to collect excess water from the primary pond during periods of high precipitation. This water may either be allowed to evaporate or be used as process makeup water during drier periods.

Rationale for Selection. The single mill currently operating in this subcategory recycles its process water following tailing-pond treatment. A discharge from this impoundment currently exists on a seasonal basis.

Levels of Effluent Reduction Attainable. Zero discharge of process water is attainable by implementation of the above technology.

Subcategory: Titanium-Ore Mills Using Physical Milling Methods In Conjunction with Dredge Mining

Identification of BATEA. The best available technology economically achievable is settling impoundment with maintenance of a pH of 3.5, secondary settling, and neutralization prior to discharge. (Same as BPCTCA.)

Category: Zirconium Ores

No separate limitations are recommended. The mining and milling of zirconium (zircon) are practiced as a part of titanium dredge mining.

SECTION XI

NEW SOURCE PERFORMANCE STANDARDS AND PRETREATMENT STANDARDS

INTRODUCTION

This level of technology is to be achieved by new sources. The term "new source" is defined in the Act to mean "any source, the construction of which is commenced after the publication of proposed regulations prescribing a standard of performance." This technology is evaluated by adding, to the consideration underlying the identification of best available technology economically achievable, a determination of what higher levels of pollution control are available through the use of improved production processes and/or treatment techniques. Thus, in addition to considering the best in-plant and end-of-process control technology, new source performance standards are how the level of effluent may be reduced by changing the production process itself. Alternative processes, operating methods, or other alternatives were considered. However, the end result of the analysis identifies effluent standards which reflect levels of control achievable through the use of improved production processes (as well as control technology), rather than prescribing a particular type of process or technology which must be employed.

The following factors were considered with respect to production processes which were analyzed in assessing the best demonstrated control technology currently available for new sources:

(a) type of process employed and process changes;
(b) operating methods;
(c) batch, as opposed to continuous, operations;
(d) use of alternative raw materials and mixes of raw materials;
(e) use of dry, rather than wet, processes (including substitution of recoverable solvents from water); and
(f) recovery of pollutants as byproducts.

In addition to the effluent limitations covering discharges directly into waterways, the constituents of the effluent discharge from a plant within the industrial category which would interfere with, pass through, or otherwise be incompatible with a well designed and operated publicly owned activated sludge or trickling filter wastewater treatment plant were identified. A determination was made whether the introduction of such pollutants into the treatment plant should be completely prohibited.

GENERAL WATER GUIDELINES

The process-water, cooling-water, and storm-water runoff guidelines for new sources are identical to those based on best available technology economically achievable.

NEW SOURCE STANDARDS BY ORE CATEGORY

Based upon the information contained in Sections III through X of this report, the following determinations were made on the degree of effluent reduction attainable with the application of new source standards for the various categories and subcategories of the ore mining and dressing industry.

The industry categories and subcategories which follow are required to achieve no discharge of process wastewater based upon best available technology economically achievable or best practicable control technology currently available.

Iron-Ore Mills - Magnetic/Physical Process (Mesabi Range)
Copper Mines and Mills - Hydrometallurgical Process
Copper Mills - Vat Leaching
Copper Mills - Froth Flotation
Lead and Zinc Mills
Gold Mills - Cyanidation Process
Gold Mills - Amalgamation Process
Gold Mills - Froth-Flotation Process
Silver Mills - Froth-Flotation Process
Silver Mills - Cyanidation Process
Silver Mills - Amalgamation Process
Mercury Mills - Gravity-Separation Process
Mercury Mills - Flotation Process
Uranium (Ra, V) Mills - Acid or Alkaline Leach Process
Antimony Mills - Flotation Process
Beryllium Mines
Beryllium Mills
Rare-Earth Mines
Rare-Earth Mills
Titanium Mills - Electrostatic, Magnetic or Gravity Processes or Flotation Processes

The same limitations are recommended as new source standards.

New source standards identical to BPCTCA limitations are recommended for the following industry categories:

- Bauxite Mines
- Silver Mills (Mine/Mills) - Gravity Separation
- Mercury Mines
- Antimony Mines
- Titanium Mines (Lode Ore)
- Platinum Mills and Mines
- Ferroalloy - Ore Mills and Mines Processing less than 5,000 metric tons (5,512 short tons) per year
- Titanium Mills - Physical Processes with Dredge Mining

New source standards identical to BATEA limitations are recommended for:

- Copper-Ore Mines
- Lead and Zinc Mines
- Gold Mines
- Gold Mills (Mine/Mills) - Gravity Separation
- Silver Mines
- Iron Ore Mines
- Iron Ore Mills - Physical and Chemical Separation and Mills Employing Only Physical Separation (Magnetic and Non-Magnetic)
- Ferroalloy-Ore Mills - Leaching Processes

Separate new source standards are recommended for the following categories or subcategories as discussed on the pages which follow:

- Ferroalloy-Ore Mines processing more than 5,000 metric tons (5,512 short tons) per year
- Ferroalloy-Ore Mills (more than 5,000 metric tons (5,512 short tons) per year) - Flotation Processes
- Uranium Mines
- Ferroalloy-Ore Mills Processing more than 5,000 metric tons (5,512 short tons) per year - Physical Methods

Category: Ferroalloy Ores

Subcategory: Ferroalloy Mines Processing More Than 5,000 Metric Tons (5,512 Short Tons) Per Year.

Identification of NSPS. For new operations, based upon information contained in Sections III - X, a determination has been made that the technology applicable to new sources is identical to BATEA with the exception of coprecipitation or ion exchange for molybdenum removal. Therefore, the technology recommended for use is lime precipitation in conjunction with a settling pond, flocculant addition, and secondary settling.

Rationale for Selection. The selection of the above technology is made on the basis of the best available, demonstrated technology. The use of coprecipitation or ion exchange is not recommended for a new source performance standard because neither of these technologies has as yet been demonstrated, and both will require some development prior to application in this subcategory.

Level of Effluent Reduction Attainable. The parameters selected for control and the levels of effluent reduction attainable by implementation of the above technology are presented in Table XI-1.

Subcategory: Ferroalloy - Ore Mills Processing More Than 5000 Metric Tons (5512 Short Tons) Per Year - Physical Methods.

Identification of NSPS. For new operations, based upon information contained in Sections III - X, a determination has been made that the technology applicable to new sources is identical to BATEA with the exception of coprecipitation or ion exchange for molybdenum removal. Therefore, the technology recommended for use is lime precipitation in conjunction with a settling pond, flocculant addition, and secondary settling.

Rationale for Selection. The selection of the above technology is made on the basis of the best available, demonstrated technology. The use of coprecipitation or ion exchange is not recommended for a new source performance standard because neither of these technologies has as yet been demonstrated, and both will require some development prior to application in this subcategory.

Level of Effluent Reduction Attainable. The parameters selected for control and the levels of effluent reduction attainable by implementation of the above technology are presented in Table XI-2.

TABLE XI-1. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR NSPS – FERROALLOY-ORE MINES PRODUCING > 5,000 METRIC TONS (5,512 SHORT TONS) PER YEAR

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
As	0.5	1.0
Cd	0.05	0.1
Cu	0.05	0.1
Mo	†	†
Pb	0.1	0.2
Zn	0.1	0.2

*Value in pH units

†No limitation proposed for NSPS

TABLE XI-2. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR NSPS-FERROALLOY-ORE MILLS PROCESSING MORE THAN 5,000 METRIC TONS (5,512 SHORT TONS) PER YEAR BY PHYSICAL METHODS

PARAMETER	CONCENTRATION (mg/ ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
As	0.5	1.0
Cd	0.05	0.1
Cu	0.05	0.1
Mo	†	†
Zn	0.1	0.2

*Value in pH units

† No limitation proposed for NSPS

Subcategory: *Mills Processing More Than 5,000 Metric Tons (,50) Short Tons) of Ferroalloy Ores per Year by Flotation Methods*

Identification of NSPS. The information contained in Sections III through X indicates that the best available, demonstrated technology applicable to new sources in this subcategory is settling, process-water recycle, and oxidation (aeration, chlorination, or ozonation). This technology is identical to BATEA with the exception of ion exchange or coprecipitation.

Rationale for Selection. The reasons for selection are discussed in detail in Section X. The use of ion exchange or coprecipitation for removal of molybdenum and is not specified for this level because the technologies have not yet been demonstrated and will require some development prior to application in this subcategory.

Level of Effluent Reduction Attainable. The parameters selected for control and the levels of effluent reduction attainable by implementation of the above technology are presented in Table XI-3.

Category: *Uranium Ores*

Subcategory: *Uranium Mines*

Identification of NSPS. Based on information contained in Sections III through X of this report, the best available, demonstrated technology applicable to new sources in this subcategory is the use of settling ponds, lime precipitation, sulfide precipitation, ion exchange (for uranium removal), barium chloride coprecipitation (for radium removal), secondary settling, and aeration.

Rationale for Selection. All technology selected for use in this subcategory to attain NSPS levels has been demonstrated, in the ore mining and dressing industry or in the chlor-alkali industry. The requirement for ion-exchange treatment (for molybdenum and vanadium removal) is not included at this level because this technology has not yet been demonstrated and will require some development prior to application in this subcategory.

Levels of Effluent Reduction Attainable. The parameters selected and the levels of effluent reduction attainable by implementation of the above technology are presented in Table XI-4.

TABLE XI-3. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR NSPS—FERROALLOY-ORE MILLS USING FLOTATION PROCESS

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24 hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
COD	25	50
Cyanide	0.02	0.04
As	0.5	1.0
Cd	0.05	0.1
Cu	0.05	0.1
Mo	†	†
Zn	0.1	0.2

*Value in pH units

†No limitation proposed for NSPS

TABLE XI-4. PARAMETERS SELECTED AND EFFLUENT LIMITATIONS RECOMMENDED FOR NSPS–URANIUM MINES

PARAMETER	CONCENTRATION (mg/ℓ) IN EFFLUENT	
	30-day average	24-hour maximum
pH	6* to 9*	6* to 9*
TSS	20	30
COD	50	100
As	0.5	1.0
Cd	0.05	0.1
Mo	**	**
V	**	**
Zn	0.1	0.2
Ra 226	3 †	10 †
U	2	4

*Values in pH units
†Values in picocuries per liter
**No limitation proposed for NSPS

PRETREATMENT STANDARDS

Recommended pretreatment guidelines for discharge of plant wastewater into public treatment works conform in general with EPA Pretreatment Standards for Municipal Sewer Works as published in the July 19, 1973 Federal Register and "Title 40 - Protection of the Environment, Chapter 1 - Environmental Protection Agency, Subchapter D - Water Programs - Part 128 - Pretreatment Standards," a subsequent EPA publication. The following definitions conform to these publications.

Compatible Pollutant

The term "compatible pollutant" means biochemical oxygen demand, suspended solids, pH and fecal coliform bacteria, plus additional pollutants identified in the NPDES permit, if the publicly owned treatment works was designed to treat such pollutants, and, in fact, does remove such pollutants to a substantial degree. Examples of such additional pollutants may include.

chemical oxygen demand
total organic carbon
phosphorus and phosphorus compounds
nitrogen and nitrogen compounds
fats, oils, and greases of animal or vegetable origin except as defined below in Prohibited Wastes.

Incompatible Pollutant

The term "incompatible pollutant" means any pollutant which is not a compatible pollutant as defined above.

Joint Treatment Works

Publicly owned treatment works for both non-industrial and industrial wastewater.

Major Contributing Industry

A major contributing industry is an industrial user of the publicly owned treatment works that: has a flow of 189.2 cubic meters (50,000 gallons) or more per average work day; has a flow greater than five percent of the flow carried by the municipal system receiving the waste; has, in its waste, a toxic pollutant in toxic amounts as defined in standards issued under Section 307 (a) of the Act; or is found by the permit issuance authority, in connection with the issuance of an NPDES permit to the publicly owned treatment works receiving the waste, to have significant impact, either singly or in combination with other contributing industries, on that treatment works or upon the quality of effluent from that treatment works.

Pretreatment

Treatment of wastewaters from sources before introduction into the publicly owned treatment works.

Prohibited Wastes

No waste introduced into a publicly owned treatment works shall interfere with the operation or performance of the works. Specifically, the following wastes shall not be introduced into the publicly owned treatment works:

a. Wastes which create a fire or explosion hazard in the publicly owned treatment works;

b. Wastes which will cause corrosive structural damage to treatment works, but in no case wastes with a pH lower than 5.0, unless the works are designed to accommodate such wastes;

c. Solid or viscous wastes in amounts which would cause obstruction to the flow in sewers, or other interference with the proper operation of the publicly owned treatment works; and

d. Wastes at a flow rate and/or pollutant discharge rate which is excessive over relatively short time periods so that there is a treatment process upset and subsequent loss of treatment efficiency.

Pretreatment for Incompatible Pollutants

In addition to the above, the pretreatment standard for incompatible pollutants introduced into a publicly owned treatment works by a major contributing industry shall be best practicable control technology currently available; provided that, if the publicly owned treatment works which receives the pollutants is committed, in its NPDES permit, to remove a specified percentage of any incompatible pollutant, the pretreatment standard applicable to users of such treatment works shall be correspondingly reduced for that pollutant; and provided further that the definition of best practicable control technology currently available for industry categories may be segmented for application to pretreatment if the Administrator determines that the definition for direct discharge to navigable waters is not appropriate for industrial users of joint treatment works.

Recommended Pretreatment Guidelines

In accordance with the preceding Pretreatment Standards for Municipal Sewer Works, the following are recommended for Pretreatment Guidelines for the wastewater effluents:

a. No pretreatment is required for removal of compatible pollutants. In addition to the list of compatible pollutants in the above paragraphs, total organic carbon, and chemical oxygen demand were found to be compatible for this industry.

b. Suspended-solids, at the high concentrations often found in untreated effluent from point sources within this industrial category, effectively constitute an incompatible pollutant. Many of the wastewaters encountered in this study require settling or sedimentation to lower the suspended-solids levels to 500 mg/l or less prior to conveyance to a publicly owned treatment works.

c. Pollutants such as phosphorus and phosphorus compounds; nitrogen and nitrogen compounds; and fats, oils, and greases need not be removed, provided that the publicly owned treatment works were designed to treat such pollutants and will accept them. Otherwise, levels should be at or below the recommendation period for BPCTCA.

d. A pH range of 6 to 9 is desirable for wastewater treatment by biological methods.

e. Hazardous pollutants such as cyanides, chromates, heavy metals, and other substances which would interfere with microorganisms responsible for organic-substance degradation in a treatment facility should be restricted to those quantities recommended in Section IX Guidelines for Best Practicable Control Technology Currently Available.

Most of the mining and milling operations are located in isolated, rural regions and have no access to municipal treatment facilities.

In addition, the hydraulic loading to the treatment systems should be as uniform as possible to maximize treatment efficiency; therefore, the large volumes and high seasonal discharges encountered in the ore mining and dressing industry may have adverse effects upon treatment efficiencies.

In the relatively few instances where municipal treatment systems may be used because of proximity, it may be necessary to use chemical treatment and settling, pH control, and flow equalization or regulation.

SECTION XII

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Brush Wellman Company
Bunker Hill Company
Carlin Gold Mining Company
Cities Service Company
Cleveland-Cliffs Iron Company
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Erie Mining Company
Goodnews Bay Mining Company
Hanna Mining Company
Homestake Mining Company
Idarado Mining Company
Inspiration Consolidated Copper Company
Jones and Laughlin Steel Corporation
Kennecot Copper Corporation
Kerramerican, Inc.

Kerr McGee Corporation
Knob Hill Mines, Inc.
Magma Copper Company
Marquette Iron Mining Company
Molybdenum Corporation of America
National Lead Industries, Inc.
New Jersey Zinc Company
Oat Hill Mining Company
Olgleby-Norton Company - Eveleth Taconite
Phelps Dodge Corporation
Pickands Mather and Company - Erie Mining Company
Ranchers Exploration and Development Corporation
Rawhide Mining Company
Reynolds Mining Corporation
Standard Metals Corporation
St. Joe Minerals Company
Sunshine Mining Company
Titanium Enterprises, Inc.
Union Carbide Corporation
United Nuclear Corporation
U.S. Antimony Corporation
U.S. Steel Corporation

SECTION XIII

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SECTION XIV

GLOSSARY

absorption - The process by which a liquid is drawn into and tends to fill permeable pores in a porous solid body; also the increase in weight of a porous solid body resulting from the penetration of liquid into its permeable pores.

acid copper - Copper electrodeposited from an acid solution of a copper salt, usually copper sulfate.

acid cure - In uranium extraction, sulfation of moist ore before leach.

acid leach - (a) Metallurgical process for dissolution of values by means of acid solution (used on sandstone ores of low lime content); (b) In the copper industry, a technology employed to recover copper from low grade ores and mine dump materials when oxide (or mixed oxide-sulfide, or low grade sulfide) mineralization is present, by dissolving the copper minerals with either sulfuric acid or sulfuric acid containing ferric iron. Four methods of leaching are employed: dump, heap, in-situ, and vat (see appropriate definitions).

acid mine water - (a) Mine water which contains free sulfuric acid, mainly due to the weathering of iron pyrites; (b) Where sulfide minerals break down under the chemical influence of oxygen and water, the mine water becomes acidic and can corrode ironwork.

activator, activating agent - A substance which when added to a mineral pulp promotes flotation in the presence of a collecting agent. It may be used to increase the floatability of a mineral in a froth, or to reflect a depressed (sunk mineral).

adit - (a) A horizontal or nearly horizontal passage driven from the surface for the working or dewatering of a mine; (b) A passage driven into a mine from the side of a hill.

adsorption - The adherence of dissolved, colloidal, or finely divided solids on the surface of solids with which they are brought into contact.

aeroflocs - Synthetic water-soluble polymers used as flocculating agents.

all sliming - (a) Crushing all the ore in a mill to so fine a state that only a small percentage will fail to pass through a 200-mesh screen; (b) Term used for treatment of gold ore which is ground to a size sufficiently fine for agitation as a cyanide pulp, as opposed to division into coarse sands for static leaching and fine slimes for agitation.

alluminothermic process - The reduction of oxides in an exothermic reaction with finely divided aluminum.

alluvial deposit; placer deposit - Earth, sand, gravel or other rock or mineral materials transported by and laid down by flowing water. Alluvial deposits generally take the form of (1) surface deposits; (2) river deposits; (3) deep leads; and (4) shore deposits.

alunite - A basic potassium aluminum sulfate, $KAl_3(OH)_6(SO_4)_2$. Closely resembles kaolinite and occurs in similar locations.

amalgamation - The process by which mercury is alloyed with some other metal to produce amalgam. It was used extensively at one time for the extraction of gold and silver from pulverized ores, now is largely superseded by the cyanide process.

AN-FO - Ammonium nitrate - fuel oil blasting agents.

asbestos minerals - Certain minerals which have a fibrous structure, are heat resistant, chemically inert and possessing high electrical insulating qualities. The two main groups are serpentine and amphiboles. Chrysotile (fibrous serpentine, $3MgO . 2SiO_2 . 2H_2O$) is the principal commercial variety. Other commercial varieties are amosite, crocidolite, actinolite, anthophyllite, and tremolite.

azurite - A blue carbonate of copper, $Cu_3(CO_3)_2(OH)_2$, crystallizing in the monoclinic system. Found as an alteration product of chalcopyrite and other sulfide ores of copper in the upper oxidized zones of mineral veins.

bastnasite; bastnaesite - A greasy, wax-yellow to reddish-brown weakly radioactive mineral, $(Ce,La)(CO_3)F$, most commonly found in contact zones, less often in pegmatites.

bauxite - (a) A rock composed of aluminum hydroxides, essentially $Al_2O_3 \cdot 2H_2O$. The principal ore of aluminum; also used collectively for lateritic aluminous ores. (b) Composed of aluminum hydroxides and impurities in the form of free silica, clay, silt, and iron hydroxides. The primary minerals found in such deposits are boehmite, gibbsite, and diaspore.

Bayer Process - Process in which impure aluminum in bauxite is dissolved in a hot, strong, alkalai solution (normally NaOH) to form sodium aluminate. Upon dilution and cooling, the solution hydrolyzes and forms a precipitate of aluminum hydroxide.

bed - The smallest division of a stratified series and marked by a more or less well-defined divisional plane from the materials above and below.

beneficiation - (a) The dressing or processing of ores for the purpose of (1) regulating the size of a desired product, (2) removing unwanted constituents, and (3) improving the quality, purity, assay grade of a desired product; (b) Concentration or other preparation of ore for smelting by drying, flotation, or magnetic separation.

Best Available Technology Economically Achievable - The level of technology applicable to effluent limitations to be achieved by July 1, 1983, for industrial discharges to surface waters as defined by Section 301(b)(1)(A) of the Act.

Best Practicable Control Technology Currently Available - The level of technology applicable to effluent limitations to be achieved by July 1, 1977, for industrial discharges to surface waters as defined by Section 301(b)(1)(A) of the Act.

byproduct - A secondary or additional product.

carbon absorption - A process utilizing the efficient absorption characteristics of activated carbon to remove both dissolved and suspended substances.

carnotite - A bright yellow uranium mineral, $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$.

cationic collectors - In flotation, amines and related organic compounds capable of producing positively charged hydrocarbon-bearing ions for the purpose of floating miscellaneous minerals, especially silicates.

cationic reagents - In flotation, surface active substances which have the active constituent in the positive ion. Used to flocculate and to collect minerals that are not flocculated by the reagents, such as oleic acid or soaps, in which the surface-active ingredient is the negative ion.

cement copper - Copper precipitated by iron from copper sulfate solutions.

cerium metals - Any of a group of rare-earth metals separable as a group from other metals occurring with them and in addition to cerium includes lanthanum, praseodymium, neodymium, promethium, samarium and sometimes europium.

cerium minerals - Rare earths; the important one is monazite.

chalcocite - Copper sulfide, Cu_2S.

chalcopyrite - A sulfide of copper and iron, $CuFeS_2$.

chert - Cryptocrystalline silica, distinguished from flint by flat fracture, as opposed to conchoidal fracture.

chromite - Chrome iron ore, $FeCr_2O_4$.

chrysocolla - Hydrated copper silicate, $CuSiO_3 \cdot 2H_2O$.

chrysotile - A metamorphic mineral, an asbestos, the fibrous variety of serpentine. A silicate of magnesium, with silica tetrahedra arranged in sheets.

cinnabar - Mercury sulfide, HgS.

claim - The portion of mining ground held under the Federal and local laws by one claimant or association, by virtue of one location and record. A claim is sometimes called a 'location'.

clarification - (a) The cleaning of dirty or turbid liquids by the removal of suspended and colloidal matter; (b) The concentration and removal of solids from circulating water in order to reduce the suspended solids to a minimum; (c) In the leaching process, usually from pregnant solution, e.g., gold-rich cyanide prior to precipitation.

classifier - (a) A machine or device for separating the constituents of a material according to relative sizes and densities thus facilitating concentration and treatment. Classifiers may be hydraulic or surface-current box classifiers. Classifiers are also used to separate sand from slime, water from sand, and water from slime; (b) The term classifier is used in particular where an upward current of water is used to remove fine particles from coarser material; (c) In mineral dressing, the classifier is a device that takes the ball-mill discharge and separates it into two portions--the finished product which is ground as fine as desired, and oversize material.

coagulation - The binding of individual particles to form flocs or agglomerates and thus increase their rate of settlement in water or other liquid (see also flocculate).

coagulator - A soluble substance, such as lime, which when added to a suspension of very fine solid particles in water causes these particles to adhere in clusters which will settle easily.

Used to assist in reclaiming water used in flotation.

collector - A heteropolar compound containing a hydrogen-carbon group and an ionizing group, chosen for the ability to adsorb selectively in froth flotation processes and render the adsorbing surface relatively hydrophobic. A promoter.

columbite; tantalite; niobite - A natural oxide of niobium (columbium), tantalum, ferrous iron, and manganese, found in granites and pegmatites, $(Fe,Mn)(Nb,Ta)_2O_6$.

concentrate - (a) In mining, the product of concentration; (b) To separate ore or metal from its containing rock or earth; (c) The enriched ore after removal of waste in a beneficiation mill, the clean product recovered in froth flotation.

concentration - Separation and accumulation of economic minerals from gangue.

concentrator - (a) A plant where ore is separated into values (concentrates) and rejects (tails). An appliance in such a plant, e.g., flotation cell, jig, electromagnet, shaking table. Also called mill; (b) An apparatus in which, by the aid of water or air and specific gravity, mechanical concentration of ores is performed.

conditioners - Those substances added to the pulp to maintain the proper pH to protect such salts as NaCN, which would decompose in an acid circuit, etc. Na_2CO_3 and CaO are the most common conditioners.

conditioning - Stage of froth-flotation process in which the surfaces of the mineral species present in a pulp are treated with appropriate chemicals to influence their reaction when the pulp is aerated.

copper minerals - Those of the oxidized zone of copper deposits (zone of oxidized enrichment) include azurite, chrysocolla, copper metal, cuprite, and malachite. Those of the underlying zone (that of secondary sulfide enrichment) include bornite, chalcocite, chalcopyrite, covellite.

The zone of primary sulfides (relatively low in grade) includes the unaltered minerals bornite and chalcopyrite.

crusher - A machine for crushing rock or other materials. Among the various types of crushers are the ball-mill, gyratory crusher, Hadsel mill, hammer mill, jaw crusher, rod mill, rolls, stamp mill, and tube mill. cuprite - A secondary copper mineral, Cu_2O.

cyanidation - A process of extracting gold and silver as cyanide slimes from their ores by treatment with dilute solutions of potassium cyanide and sodium cyanide.

cyanidation vat - A large tank, with a filter bottom, in which sands are treated with sodium cyanide solution to dissolve out gold.

cyclone - (a) The conical-shaped apparatus used in dust collecting operations and fine grinding applications; (b) A classifying (or concentrating) separator into which pulp is fed, so as to take a circular path. Coarser and heavier fractions of solids report at the apex of long cone while finer particles overflow from central vortex.

daughter - Decay product formed when another element undergoes radioactive disintegration.

decant structure - Apparatus for removing clarified water from the surface layers of tailings or settling ponds. Commonly used structure include decant towers in which surface waters flow over a gate (adjustable in height) and down the tower to a conduit generally buried beneath the tailings, decant weirs over which water flows to a channel external to the tailings pond, and floating decant barges which pump surface water out of the pond.

dense-media separation - (a) Heavy media separation, or sink float. Separation of heavy sinking from light floating mineral particles in a fluid of intermediate density; (b) Separation of relatively light (floats) and heavy ore particles (sinks), by immersion in a bath of intermediate density.

Denver cell - A flotation cell of the subaeration type, in wide use. Design modifications include recededdisk, conical-disk, and multibladed impellers, low-pressure air attachments, and special froth withdrawal arrangements.

Denver jig - Pulsion-suction diaphragm jig for fine material, in which makeup (hydraulic) water is admitted through a rotary valve adjustable as to portion of jigging cycle over which controlled addition is made.

deposit - Mineral or ore deposit is used to designate a natural occurrence of a useful mineral or an ore, in sufficient extent and degree of concentration to invite exploitation.

depressing agent; depressor - In the froth flotation process, a substance which reacts with the particle surface to render it less prone to stay in the froth, thus causing it to wet down as a tailing product (contrary to activator).

detergents, synthetic - Materials which have a cleansing action like soap but are not derived directly from fats and oils. Used in ore flotation.

development work - Work undertaken to open up ore bodies as distinguished from the work of actual ore extraction or exploratory work.

dewater - To remove water from a mine usually by pumping, drainage or evaporation.

differential flotation - Separating a complex ore into two or more valuable minerals and gangue by flotation; also called selective flotation. This type of flotation is made possible by the use of suitable depressors and activators.

discharge - Outflow from a pump, drill hole, piping system, channel, weir or other discernible, confined or discrete conveyance (see also point source).

dispersing agent - Reagent added to flotation circuits to prevent flocculation, especially of objectionable colloidal slimes. Sodium silicate is frequently added for this purpose.

dredge; dredging - A large floating contrivance for underwater excavation of materials using either a chain of buckets, suction pumps, or other devices to elevate and wash alluvial deposits and gravel for gold, tin, platinum, heavy minerals, etc.

dressing - Originally referred to the picking, sorting, and washing of ores preparatory to reduction. The term now includes more elaborate processes of milling and concentration of ores.

drift mining - A term applied to working alluvial deposits by underground methods of mining. The paystreak is reached through an adit or a shallow shaft. Wheelbarrows or small cars may be used for transporting the gravel to a sluice on the surface.

dump leaching - Term applied to dissolving and recovering minerals from subore-grade materials from a mine dump. The dump is irrigated with water, sometimes acidified, which percolates into and through the dump, and runoff from the bottom of the dump is collected, and a mineral in solution is recovered by chemical reaction. Often used to extract copper from low grade, waste material of mixed oxide and sulfide mineralization produced in open pit mining.

effluent - The wastewater discharged from a point source to navigable waters.

electrowinning - Recovery of a metal from an ore by means of electrochemical processes, i.e., deposition of a metal on an electrode by passing electric current through an electrolyte.

eluate - Solutions resulting from regeneration (elution) of ion exchange resins.

eluent - A solution used to extract collected ions from an ion exchange resin or solvent and return the resin to its active state.

exploration - Location of the presence of economic deposits and establishing ther nature, shape, and grade and the investigation may be divided into (1) preliminary and (2) final.

extraction - (a) The process of mining and removal of ore from a mine. (b) The separation of a metal or valuable mineral from an ore or concentrate. (c) Used in relation to all processes that are used in obtaining metals from their ores. Broadly, these processes involve the breaking down of the ore both mechanically (crushing) and chemically (decomposition), and the separation of the metal from the associated gangue.

ferruginous - containing iron.

ferruginous chert - A sedimentary deposit consisting of chalcedony or of fine-grained quartz and variable amounts of hematite, magnetite, or limonite.

ferruginous deposit - A sedimentary rock containing enough iron to justify exploitation as iron ore. The iron is present, in different cases, in silicate, carbonate, or oxide form, occurring as the minerals chamosite, thuringite, siderite, hematite, limonite, etc.

flask - A unit of measurement for mercury; 76 pounds.

flocculant - An agent that induces or promotes flocculation or produces floccules or other aggregate formation, especially in clays and soils.

flocculate - To cause to aggregate or to coalesce into small lumps or loose clusters, e.g., the calcium ion tends to flocculate clays.

flocculating agent; flocculant - A substance which produces flocculation.

flotation - The method of mineral separation in which a froth created in water by a variety of reagents floats some finely crushed minerals, whereas other minerals sink.

flotation agent - A substance or chemical which alters the surface tension of water or which makes it froth easily. The reagents used in the flotation process include pH regulators, slime dispersants, resurfacing agents, wetting agents, conditioning agents, collectors, and frothers.

friable - Easy to break, or crumbling naturally.

froth, foam - In the flotation process, a collection of bubbles resulting from agitation, the bubbles being the agency for raising (floating) the particles of ore to the surface of the cell.

frother(s) - Substances used in flotation processes to make air bubbles sufficiently permanent principally by reducing surface tension. Common frothers are pine oil, creyslic acid, and amyl alcohol.

gangue - Undesirable minerals associated with ore.

glory hole - A funnel-shaped excavation, the bottom of which is connected to a raise driven from an underground haulage level or is connected through a horizontal tunnel (drift) by which ore may also be conveyed.

gravity separation - Treatment of mineral particles which exploits differences between their specific gravities. Their sizes and shapes also play a minor part in separation. Performed by means of jigs, classifiers, hydrocyclones, dense media, shaking tables, Humphreys spirals, sluices, vanners and briddles.

grinding - (a) Size reduction into relatively fine particles. (b) Arbitrarily divided into dry grinding performed on mineral containing only moisture as mined, and wet grinding, usually done in rod, ball or pebble mills with added water.

heap leaching - A process used in the recovery of copper from weathered ore and material from mine dumps. The liquor seeping through the beds is led to tanks, where it is treated with scrap iron to precipitate the copper from solution.

This process can also be applied to the sodium sulfide leaching of mercury ores.

heavy-media separation - See dense-media separation.

hematite - One of the most common ores of iron, Fe_2O_3, which when pure contains about 70% metallic iron and 30% oxygen. Most of the iron produced in North America comes from the iron ranges of the Lake Superior District, especially the Mesabi Range, Minnesota. The hydrated variety of this ore is called limonite.

Huntington-Heberlein Process - A sink-float process employing a galena medium and utilizing froth flotation as the means of medium recovery.

hydraulic mining - (a) Mining by washing sand and soil away with water which leaves the desired mineral. (b) The process by which a bank of gold-bearing earth and rock is excavated by a jet of water, discharged through the converging nozzle of a pipe under great pressure. The debris is carried away with the same water and discharged on lower levels into watercourses below.

hydrolysate; hydrolyzate - A sediment consisting partly of chemically undecomposed, finely ground rock powder and partly of insoluble matter derived from hydrolytic decomposition during weathering.

hydrometallurgy - The treatment of ores, concentrates, and other metal-bearing materials by wet processes, usually involving the solution of some component, and its subsequent recovery from the solution.

ilmenite - An iron-black mineral, $FeO \cdot TiO_2$. Resembles magnetite in appearance but is readily distinguished by feeble magnetic character.

in-situ leach - Leaching of broken ore in the subsurface as it occurs, usually in abandoned underground mines which previously employed block-caving mining methods.

ion(ic) exchange - The replacement of ions on the surface, or sometimes within the lattice, of materials such as clay.

iron formation - Sedimentary, low grade, iron ore bodies consisting mainly of chert and fine-grained quartz and ferric oxide segregated in bands or sheets irregularly mingled (see also taconite).

jaw crusher - A primary crusher designed to reduce large rocks or ores to sizes capable of being handled by any of the secondary crushers.

jig - A machine in which the feed is stratified in water by means of a pulsating motion and from which the stratified products are separately removed, the pulsating motion being usually obtained by alternate upward and downward currents of the water.

jigging - (a) The separation of the heavy fractions of an ore from the light fractions by means of a jig. (b) Up and down motion of a mass of particles in water by means of pulsion. laterite - Red residual soil developed in humid, tropical, and subtropical regions of good drainage. It is leached of silica and contains concentrations particularly of iron oxides and hydroxides and aluminum hydroxides. It may be an ore of iron, aluminum, manganese, or nickel.

launder - (a) A trough, channel, or gutter usually of wood, by which water is conveyed; specifically in mining, a chute or trough for conveying powdered ore, or for carrying water to or from the crushing apparatus. (b) A flume.

leaching - (a) The removal in solution of the more soluble minerals by percolating waters. (b) Extracting a soluble metallic compound from an ore by selectively dissolving it in a suitable solvent, such as water, sulfuric acid, hydrochloric acid, etc. The solvent is usually recovered by precipitation of the metal or by other methods.

leach ion-exchange flotation process - A mixed method of extraction developed for treatment of copper ores not amenable to direct flotation. The metal is dissolved by leaching, for example, with sulfuric acid, in the presence of an ion exchange resin. The resin recaptures the dissolved metal and is then recovered in a mineralized froth by the flotation process.

leach precipitation float - A mixed method of chemical reaction plus flotation developed for such copper ores as chrysocolla and the oxidized minerals. The value is dissolved by leaching with acid, and the copper is reprecipitated on finely divided particles of iron, which are then recovered by flotation, yielding an impure concentrate in which metallic copper predominates.

lead minerals - The most important industrial one is galena (PbS), which is usually argentiferous. In the upper parts of deposits the mineral may be altered by oxidation to cerussite ($PbCO_3$) or anglesite ($PbSO_4$). Usually galena occurs in intimate association with sphalerite (ZnS).

leucoxene - A brown, green, or black variety of sphene or titanite, CaTiSiO_, occurring as monoclinic crystals. An earthy alteration product consisting in most instances of rutile; used in the production of titanium tetrachloride.

lime - Quicklime (calcium oxide) obtained by calcining limestone or other forms of calcium carbonate. Loosely used for hydrated lime (calcium hydroxide) and incorrectly used for pulverized or ground calcium carbonate in agricultural lime and for calcium in such expressions as carbonate of lime, chloride of lime, and lime feldspar.

lime slurry - A form of calcium hydroxide in aqueous suspension that contains considerable free water.

limonite - Hydrous ferric oxide, $FeO(OH) \cdot nH_2O$. An important ore of iron, occurring in stalactitic, mammillary, or earthy forms of a dark brown color, and as a yellowish-brown powder. The chief constituent of bog iron ore.

liquid-liquid extraction, solvent extraction - A process in which one or more components are removed from a liquid measure by intimate contact with a second liquid, which is itself nearly insoluble in the first liquid and dissolves the impurities and not the substance that is to be purified.

lode - A tabular deposit of valuable mineral between definite boundaries. Lode, as used by miners, is nearly synonymous with the term vein as employed by geologists.

magnetic separation - The separation of magnetic materials from nonmagnetic materials using a magnet. An important process in the beneficiation of iron ores in which the magnetic mineral is separated from nonmagnetic material, e.g., magnetite from other minerals, roasted pyrite from sphalerite.

magnetic separator - A device used to separate magnetic from less magnetic or nonmagnetic materials. The crushed material is conveyed on a belt past a magnet.

magnetite, magnetic iron ore - Natural black oxide of iron, Fe_3O_4. As black sand, magnetite occurs in placer deposits, and also as lenticular bands. Magnetite is used widely as a suspension solid in dense-medium washing of coal and ores.

malachite - A green, basic cupric carbonate, $Cu_2(OH)_2CO_3$, crystallizing in the monoclinic system. It is a common ore of copper and occurs typically in the oxidation zone of copper deposits.

manganese minerals - Those in principal production are pyrolusite, some psilomelane, and wad (impure mixture of manganese and other oxides).

manganese nodules - The concretions, primarily of manganese salts, covering extensive areas of the ocean floor. They have a layer configuration and may prove to be an important source of manganese.

manganese ore - A term used by the Bureau of Mines for ore containing 35 percent or more manganese and may include concentrate, nodules, or synthetic ore.

manganiferous iron ore - A term used by the Bureau of Mines for ores containing 5 to 10 percent manganese.

manganiferous ore - A term used by the Bureau of Mines for any ore of importance for its manganese content containing less than 35 percent manganese but not less than 5 percent manganese.

mercury minerals - The main source is cinnabar, HgS.

mill - (a) Reducing plant where ore is concentrated and/or metals recovered. (b) Today the term has been broadened to cover the whole mineral treatment plant in which crushing, wet grinding, and further treatment of the ore is conducted. (c) In mineral processing, one machine, or a group, used in comminution.

minable - (a) Capable of being mined. (b) Material that can be mined under present day mining technology and economics.

mine - (a) An opening or excavation in the earth for the purpose of excavating minerals, metal ores or other substances by digging. (b) A word for the excavation of minerals by means of pits, shafts, levels, tunnels, etc., as opposed to a quarry, where the whole excavation is open. In general the existence of a mine is determined by the mode in which the mineral is obtained, and not by its chemical or geologic character. (c) An excavation beneath the surface of the ground from which mineral matter of value is extracted. Excavations for the extraction of ore or other economic minerals not requiring work beneath the surface are designated by a modifying word or phrase as: (1) opencut mine - an excavation for removing minerals which is open to the weather; (2) steam shovel mine - an opencut mine in which steam shovels or other power shovels are used for loading cars; (3) strip mine - a stripping, an openpit mine in which the overburden is removed from the exploited material before the material is taken out; (4) placer mine - a deposit of sand, gravel or talus from which some valuable mineral is extracted; and (5) hydraulic mine - a placer mine worked by means of a stream of water directed against a bank of sand, gravel, or talus. Mines are commonly known by the mineral or metal extracted, e.g., bauxite mines, copper mines, silver mines, etc. (d) Loosely, the word mine is used to mean any place from which minerals are extracted, or ground which it is hoped may be mineral bearing. (e) The Federal and State courts have held that the word mine, in statutes reserving mineral lands, included only those containing valuable mineral deposits. Discovery of a mine: In statutes relating to mines the word discovery is used: (1) In the sense of uncovering or disclosing to view ore or mineral; (2) of finding out or bringing to the knowledge the existence of ore, or mineral, or other useful products which were unknown; and (3) of exploration, that is, the more exact blocking out or ascertainment of a deposit that has already been discovered. In this sense it is practically synonymous with development, and has been so used in the U.S. Revenue Act of February 19, 1919 (Sec. 214, subdiv. A10, and Sec. 234, subdiv. A9) in allowing depletion to mines, oil and gas wells. Article 219 of Income and War Excess Profits Tax Regulations No. 45, construes discovery of a mine as: (1) The bona fide discovery of a commercially valuable deposit of ore or mineral, of a value materially in excess of the cost of discovery in natural exposure or by drilling or other exploration conducted above or below the ground; and (2) the development and proving of a mineral or ore deposit which has been apparently worked out to be a mineable deposit or ore, or mineral having a value in excess of the cost of improving or development.

mine drainage - (a) Mine drainage usually implies gravity flow of water to a point remote from mining operation. (b) The process of removing surplus ground or surface water by artificial means.

mineral - An inorganic substance occurring in nature, though not necessarily of inorganic origin, which has (1) a definite chemical composition, or more commonly, a characteristic range of chemical composition, and (2) distinctive physical properties, or molecular structure. With few exceptions, such as opal (amorphous) and mercury (liquid), minerals are crystalline solids.

mineral processing; ore dressing; mineral dressing - The dry and wet crushing and grinding of ore or other mineral-bearing products for the purpose of raising concentrate grade; removal of waste and unwanted or deleterious substances from an otherwise useful product; separation into distinct species of mixed minerals; chemical attack and dissolution of selected values.
modifier(s) - (a) In froth flotation, reagents used to control alkalinity and to eliminate harmful effects of colloidal material and soluble salts. (b) Chemicals which increase the specific attraction between collector agents and particle surfaces, or conversely which increase the wettability of those surfaces.

molybdenite - The most common ore of molybdenum, MoS_2.

molybdenite concentrate - Commercial molybdenite ore after the first processing operations. Contains about 90% MoS_2 along with quartz, feldspar, water, and processing oil.

monazite - A phosphate of the cerium metals and the principal ore of the rare earths and thorium. Monoclinic. One of the chief sources of thorium used in the manufacture of gas mantles. It is a moderately to strongly radioactive mineral, $(Ce,La,Y,Th)PO_4$. It occurs widely disseminated as an accessory mineral in granitic igneous rocks and gneissic metamorphic rocks. Detrital sands in regions of such rocks may contain commercial quantities of monazite. Thorium-free monazite is rare.

New Source Performance Standard - Performance standards for the industry and applicable new sources as defined by Section 306 of the Act.

niccolite - A copper-red arsenide of nickel which usually contains a little iron, cobalt, and sulfur. It is one of the chief ores of metallic nickel. nickel minerals - The nickel-iron sulfide, pentlandite ($(Fe, Ni)_9S_8$) is the principal present economic source of nickel, and garnierite (nickelmagnesium hydrosilicate) is next in economic importance.

oleic acid - A mono-saturated fatty acid, $CH_3(CH_2)\_CH{:}CH(CH_2)_7$ COOH. A common component of almost all naturally occurring fats as well as tall oil. Most commercial oleic acid is derived from animal tallow or natural vegetable oils.

open-pit mining, open cut mining - A form of operation designed to extract minerals that lie near the surface. Waste, or overburden, is first removed, and the mineral is broken and loaded. Important chiefly in the mining of ores of iron and copper.

ore - (a) A natural mineral compound of the elements of which one at least is a metal. Applied more loosely to all metalliferous rock, though it contains the metal in a free state, and occasionally to the compounds of nonmetallic substances, such as sulfur. (b) A mineral of sufficient value as to quality and quantity which may be mined with profit.

ore dressing - The cleaning of ore by the removal of certain valueless portion as by jigging, cobbing, vanning and the like. Synonym for concentration. The same as mineral dressing.

ore reserve - The term is usually restricted to ore of which the grade and tonnage have been established with reasonable assurance by drilling and other means.

oxidized ores - The alteration of metalliferous minerals by weathering and the action of surface waters, and the conversion of the minerals into oxides, carbonates, or sulfates.

oxidized zone - That portion of an ore body near the surface, which has been leached by percolating water carrying oxygen, carbon dioxide or other gases.

pegmatite - An igneous rock of coarse grain size usually found as a crosscutting structure in a larger igneous mass of finer grain size.

pelletizing - A method in which finely divided material is rolled in a drum or on an inclined disk, so that the particles cling together and roll up into small, spherical pellets.

pH modifiers - Proper functioning of a cationic or anionic flotation reagent is dependent on the close control of pH. Modifying agents used are soda ash, sodium hydroxide, sodium silicate, sodium phosphates, lime, sulfuric acid, and hydrofluoric acid.

placer mine - (a) A deposit of sand, gravel, or talus from which some valuable mineral is extracted. (b) To mine gold, platinum, tin or other valuable minerals by washing the sand, gravel, etc.

placer mining - The extraction of heavy mineral from a placer deposit by concentration in running water. It includes ground sluicing, panning, shoveling gravel into a sluice, scraping by power scraper, excavation by dragline or extraction by means of various types of dredging activities.

platinum minerals - Platinum, ruthenium, rhodium, palladium, osmium, and iridium are members of a group characterized by high specific gravity, unusual resistance to oxidizing and acidic attack, and high melting point.

point source - Any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged.

pregnant solution - A value bearing solution in a hydrometallurgical operation.

pregnant solvent - In solvent extraction, the value-bearing solvent produced in the solvent extraction circuit.

promoter - A reagent used in froth-flotation process, usually called the collector.

rare-earth deposits - Sources of cerium, terbium, yttrium, and related elements of the rare-earth's group, as well as thorium.

raw mine drainage - Untreated or unprocessed water drained, pumped or siphoned from a mine.

reagent - A chemical or solution used to produce a desired chemical reaction; a substance used in assaying or in flctation.

reclamation - The procedures by which a disturbed area can be reworked to make it productive, useful, or aethetically pleasing.

recovery - A general term to designate the valuable constituents of an ore which are obtained by metallurgical treatment.

reduction plant - A mill or a treatment place for the extraction of values from ore.

roast - To heat to a point somewhat short of fusing in order to expel volatile matter or effect oxidation.

rougher cell - Flotation cells in which the bulk of the gangue is removed from the ore.

roughing - Upgrading of run-of-mill feed either to produce a low grade preliminary concentrate or to reject valueless tailings at an early stage. Performed by gravity on roughing tables, or in flotation in a rougher circuit.

rutile - Titanium dioxide, TiO_2.

scintillation counter - An instrument used for the location of radioactive ore such as uranium. It uses a transparent crystal which gives off a flash of light when struck by a gamma ray, and a photomultiplier tube which produces an electrical impulse when the light from the crystal strikes it.

selective flotation - See differential flotation.

settling pond - A pond, natural or artificial, for recovering solids from an effluent.

siderite - An iron carbonate, $FeCO_3$.

slime, slimes - A material of extremely fine particle size encountered in ore treatment.

sludge - The precipitant or settled material from a waste water.

slurry - (a) Any finely divided solid which has settled out as from thickeners. (b) A thin watery suspension.

solvent extraction - See liquid-liquid extraction.

sphalerite - Zinc sulfide, ZnS. stibnite - An antimony sulfide, Sb_2S_3. The most important ore of antimony.

suction dredge - (a) Essentially a centrifugal pump mounted on a barge. (b) A dredge in which the material is lifted by pumping through a suction pipe.

sulfide zone - That part of a lode or vein not yet oxidized by the air or surface water and containing sulfide minerals.

surface active agent - One which modifies physical, electrical, or chemical characteristics of the surface of solids and also surface tensions of solids or liquid. Used in froth flotation (see also depressing agent, flotation agent).

tabling - Separation of two materials of different densities by passing a dilute suspension over a slightly inclined table having a reciprocal horizontal motion or shake with a slow forward motion and a fast return.

taconite - (a) The cherty or jaspery rock that encloses the Mesabi iron ores in Minnesota. In a somewhat more general sense, it designates any bedded ferruginous chert of the Lake Superior District. (b) In Minnesota practice, is any grade of extremely hard, lean iron ore that has its iron either in banded or well-disseminated form and which may be hematite or magnetite, or a combination of the two within the same ore body (Bureau of Mines).

taconite ore - A type of highly abrasive iron ore now extensively mined in the United States.

tailing pond - Area closed at lower end by constraining wall or dam to which mill effluents are run.

tailings - (a) The parts, or a part, of any incoherent or fluid material separated as refuse, or separately treated as inferior in quality or value; leavings; remainders; dregs. (b) The gangue and other refuse material resulting from the washing, concentration, or treatment of ground ore. (c) Those portions of washed ore that are regarded as too poor to be treated further; used especially of the debris from stamp mills or other ore dressing machinery, as distinguished from concentrates.

tall oil - The oily mixture of rosin acids, and other materials obtained by acid treatment of the alkaline liquors from the digesting (pulping) of pine wood. Used in drying oils, in cutting oils, emulsifiers, and in flotation agents.

tantalite - A tantalate of iron and manganese $(Fe,Mn)Ta_2O_6$, crystallizing in the orthorhombic system.

tetrahedrite - A mineral, the part with Sb greater than As of the tetrahedrite-tenantite series, $Cu_3(Sb,As)_3$. Silver, zinc, iron and mercury may replace part of the copper. An important ore of copper and silver.

thickener - A vessel or apparatus for reducing the amount of water in a pulp.

thickening - (a) The process of concentrating a relatively dilute slime pulp into a thick pulp, that is, one containing a smaller percentage of moisture, by rejecting liquid that is essentially solid free. (b) The concentration of the solids in a suspension with a view to recovering one fraction with a higher concentration of solids than in the original suspension.

tin minerals - Virtually all the industrial supply comes from cassiterite(SnO_2), though some has been obtained from the sulfide minerals stannite, cylindrite, and frankeite. The bulk of cassiterite comes from alluvial workings.

titanium minerals - The main commercial minerals are rutile (TiO_2) and ilmenite ($FeTiO_3$).

tyuyamunite - A yellow uranium mineral, $Ca(UO_2)_2(VO_4)_2 \cdot 3H_2O$. It is the calcium analogue of carnotite.

uraninite - Essentially UO_2. It is a complex uranium mineral containing also rare earths, radium, lead, helium, nitrogen and other elements.

uranium minerals - More than 150 uranium bearing minerals are known to exist, but only a few are common. The five primary uranium-ore minerals are pitchblende, uraninite, davidite, coffinite, and brannerite. These were formed by deep-seated hot solutions and are most commonly found in veins or pegmatites. The secondary uranium-ore minerals, altered from the primary minerals by weathering or other natural processes, are carnotite, tyuyamunite and metatyuyamunite (both very similar to carnotite), torbernite and metatorbernite, autunite and meta-autunite, and uranophane.

vanadium minerals - Those most exploited for industrial use are patronite (VS_4), roscoelite (vanadium mica), vanadinite ($Pb\_Cl(VO_4)_3$), carnotite and chlorovanadinite.

vat leach - Employs the dissolution of copper oxide minerals by sulfuric acid from crushed, non-porous ore material placed in confined tanks. The leach cycle is rapid and measured in days.

weir - An obstruction placed across a stream for the purpose of diverting the water so as to make it flow through a desired channel, which may be an opening or notch in the weir itself.

wetting agent - A substance that lowers the surface tension of water and thus enables it to mix more readily. Also called surface active agent.

Wilfley table - A widely used form of shaking table. A plane rectangle is mounted horizontally and can be sloped about its long axis. It is covered with linoleum (occasionally rubber) and has longitudinal riffles dying at the discharge end to a smooth cleaning area, triangular in the upper corner. Gentle and rapid throwing motion is used on the table longitudinally. Sands, usually classified for size range are fed continuously and worked along the table with the aid of feedwater, and across riffles downslope by gravity tilt adjustment, and added washwater. At the discharge end, the sands have separated into bands, the heaviest and smallest uppermost, the lightest and largest lowest.

xanthate - Common specific promoter used in flotation of sulfide ores. A salt or ester of xanthic acid which is made of an alcohol, carbon disulfide and an alkalai. xenotime - A yttrium phosphate, YPO_4, often containing small quantities of cerium, terbium, and thorium, closely resembling zircon in crystal form and general appearance.

yellow cake - (a) A term applied to certain uranium concentrates produced by mills. It is the final precipitate formed in the milling process. It is usually considered to be ammonium diuranate, $(NH_4)_2U_2O_7$, or sodium diuranate, $Na_2U_2O_7$, but the composition is variable and depends upon the precipitating conditions. (b) A common form of triuranium octoxide, U_3O_8, is yellow cake, which is the powder obtained by evaporating an ammonia solution of the oxide.

zinc minerals - The main source of zinc is sphalerite (ZnS), but some smithsonite, hemimorphite, zincite, willemite, and franklinite are mined.

zircon - A mineral, $ZrSiO_4$. The chief ore of zirconium.

zircon, rutile, ilmenite, monazite - A group of heavy minerals which are usually considered together because of their occurrence as black sand in natural beach and dune concentration. to discharge may be necessary. prior to discharge may be necessary. presented in this section will be consolidated, where possible, in the regulations derived from this development document.

SECTION XV

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